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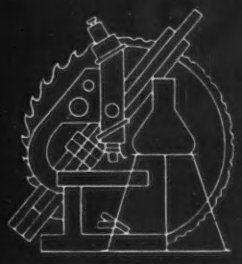
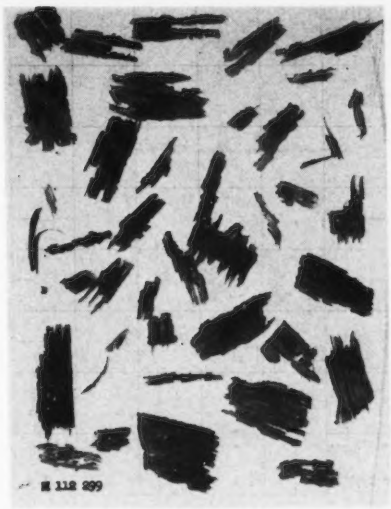
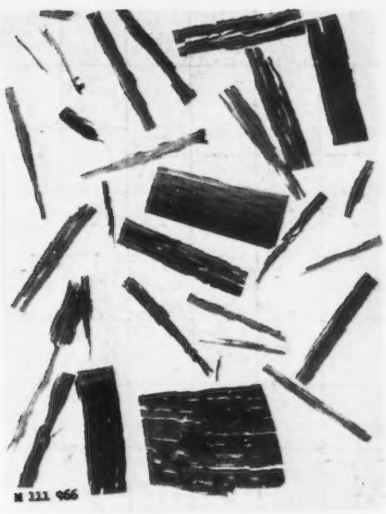
Forest Products Journal



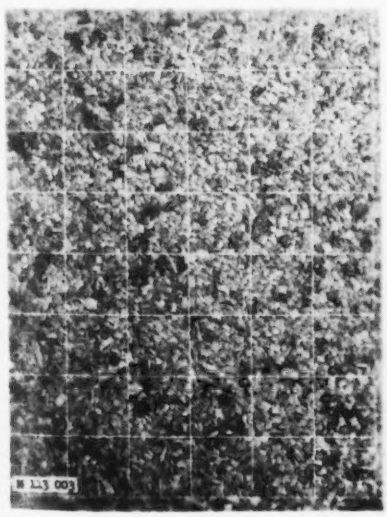
Sawdust Particles



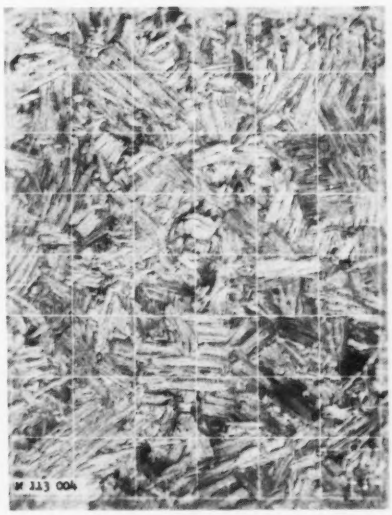
Planer Shavings



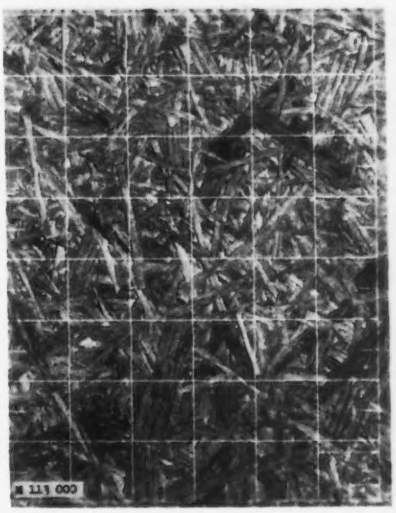
Flake Particles



Sawdust Board



Planer Shavings Board



Flake Board

Oak Particle Board Characteristics Affected by Particle Size . . . Page 197

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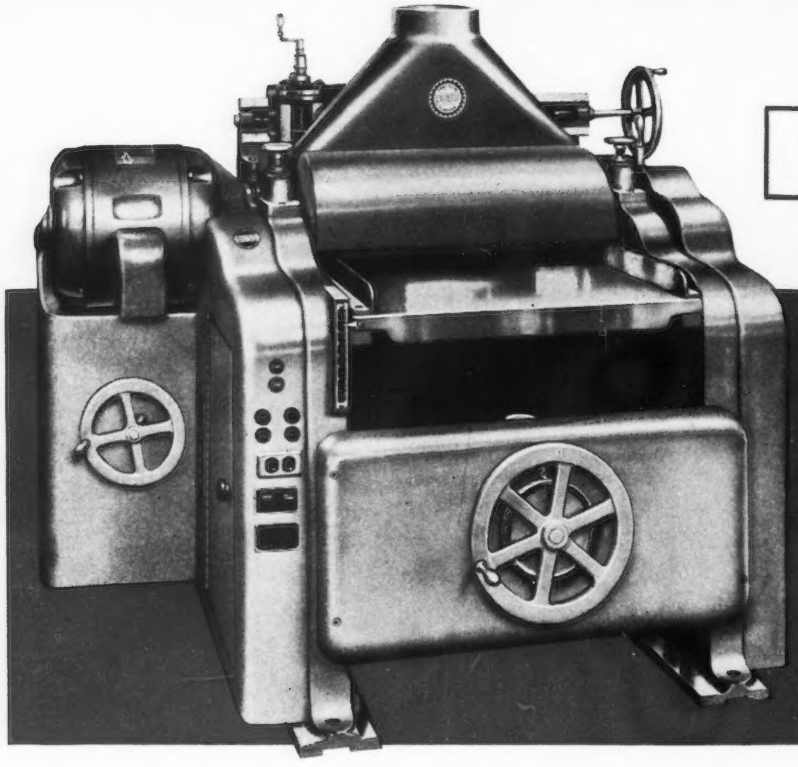

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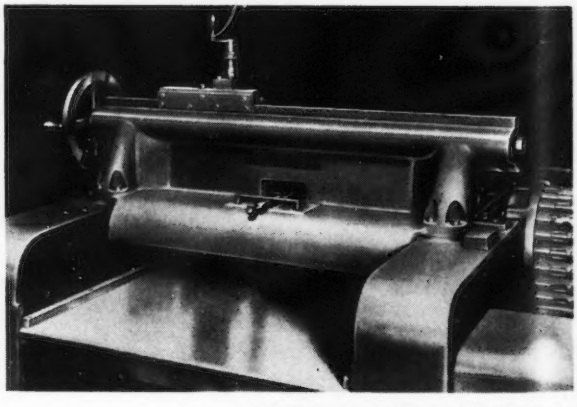

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FOREST PRODUCTS JOURNAL

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Correspondence on editorial matters should be addressed to the Editor, at the Executive Office. The Society is not responsible for views expressed in publications.

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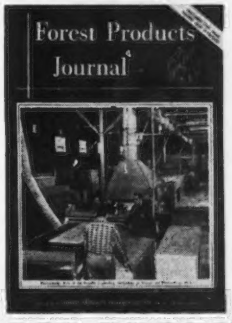
and Practical Production-Management Man . . .

Both Read the Authoritative and Unabridged . . .



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Photo, Unit Structures

Penacolite Adhesives were used in exterior laminations of the Jai Alai Fronton, Riviera Beach, Florida. These arches, some of the largest ever laminated, span 247 feet from side to side. They taper from 20 inches at the crown to 46 inches at the center, with a rise of 74 feet.

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Keel of the navy minehunter, U.S.S. Bittern, the first modern naval vessel to have a laminated keel and ribs of pressure-treated wood. All timbers in this ship were bonded with Penacolite.

Photo, Unit Structures, Inc.

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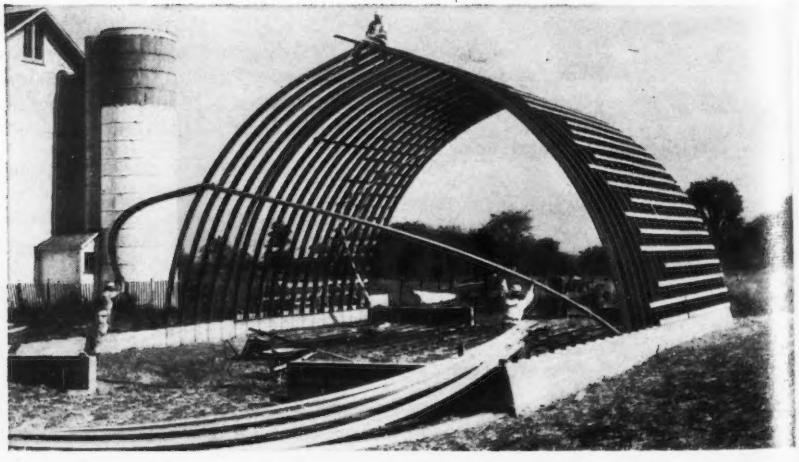
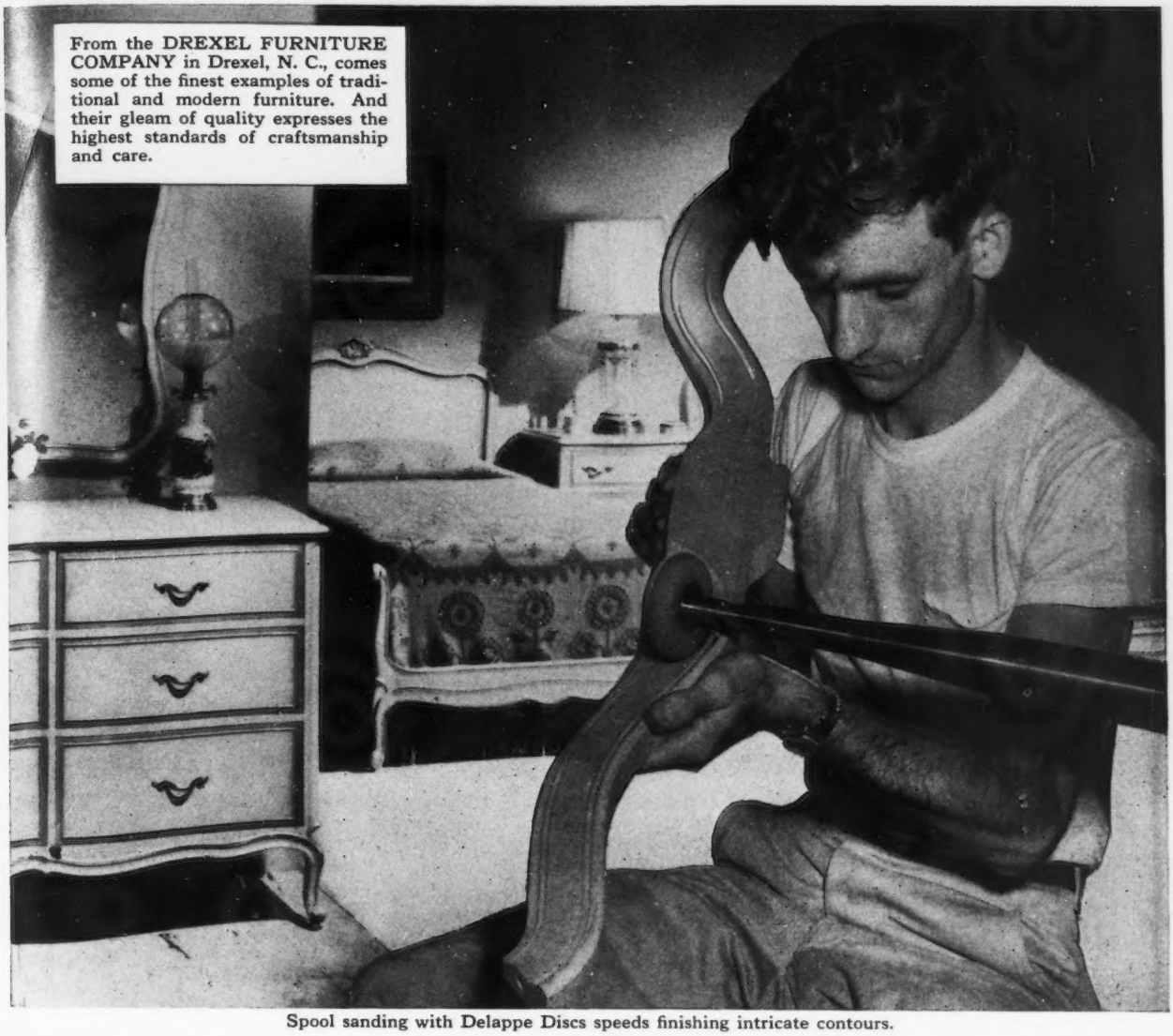
Machine shed under construction. Kiln-dried Douglas Fir rafters, laminated with Penacolite Adhesives, are 4 times stronger than nailed rafters. These bonded rafters give the strength of single, solid, joint-free members, from the foundation to the roof ridge.

Photo, Rilco Laminated Products, Inc.



PARTNERS IN PROGRESS AND LEADERSHIP...



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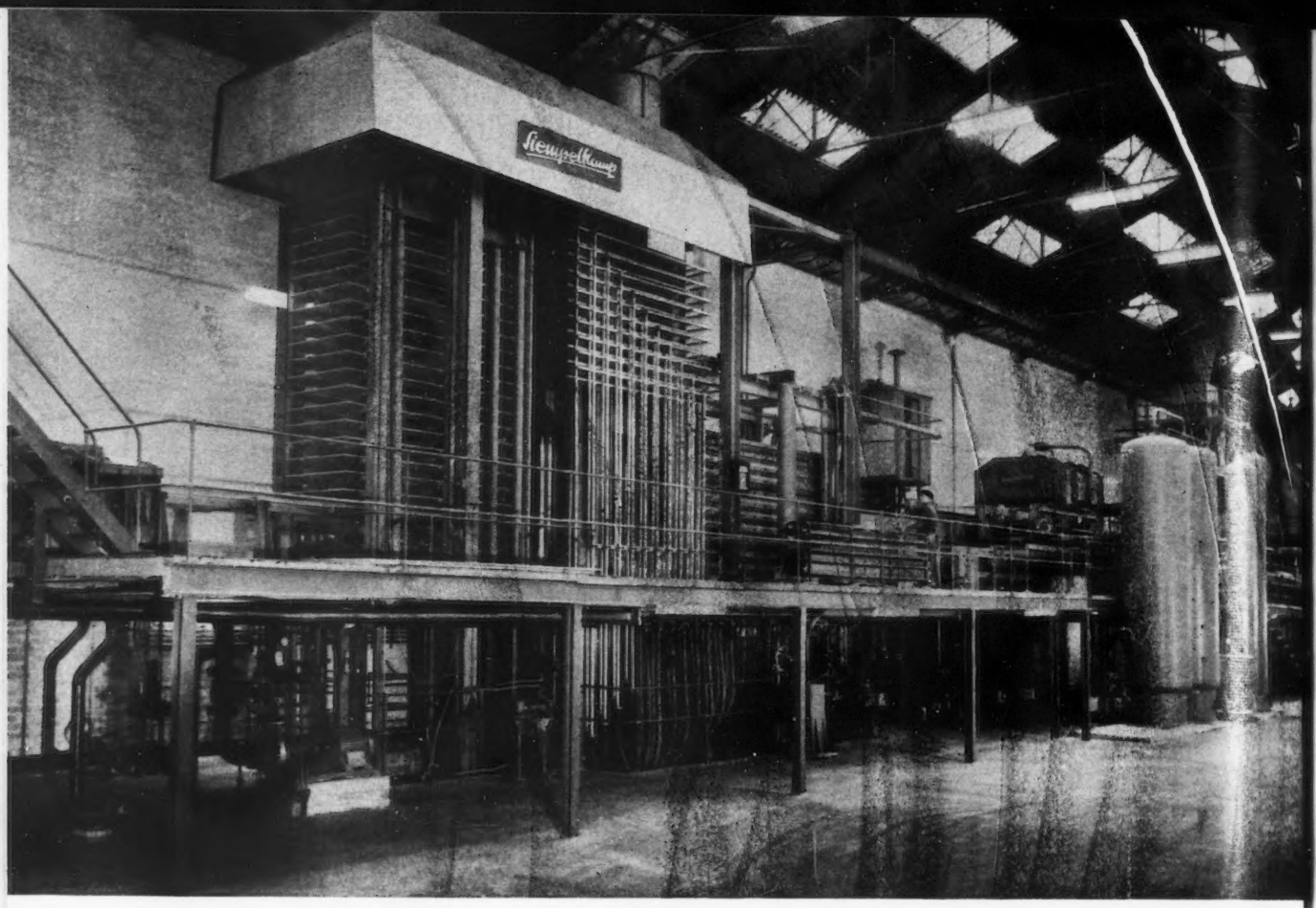

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FPRS News-Digest

FPRS' Pacific Northwest and Inland Empire Sections Join A.S.M.E. and A.I.Ch.E. in "Wood Industries Conference," Sept. 10-12 at Portland Ore.

LONGVIEW, WASH. MILL of Weyerhaeuser Timber Co., world's largest integrated sawmill-plywood operation.

LONG–BELL DIV., International Paper Co., at Longview, Wash., contains flakeboard, Super Microseal and cabinet operations.

OVER 2,700 PERSONS in the United States and Canada have been invited to attend the Wood Industries Conference to be held at the Multnomah Hotel, in Portland, Oregon, on September 10, 11 and 12, according to H. A. McKeever, Weyerhaeuser Timber Co., General Chairman.

Assisting Mr. McKeever are co-chairmen Charles M. Kreider, chairman of Inland Empire Section F.P.R.S., and Phil L. Northcott, chairman of Pacific Northwest Section, F.P.R.S.

Other sponsoring societies are, the American Society of Mechanical Engineers, Wood Industries Division; and the American Institute of Chemical Engineers, Washington–Oregon Section and the Southwest Washington Section.

Registration

Registration will begin at 7 P. M. September 9 and continue until 10 P. M. An "Early Bird" social hour is scheduled that evening.

Fees of $7.00 for members and $10.00 for non-members will include admission to all technical sessions.

Luncheon and Banquet

A luncheon meeting is scheduled for noon Thursday, September 10, and will feature a speaker of national prominence to be announced at a later date. The banquet meeting is scheduled at 7 P. M. Thursday, September 10. Guest speaker will be Stewart Holbrook, noted author and chronicler of the Northwest forest industry.

SESSION I Foundations for Profitable Research

Thursday, Sept. 10, 8:30–11:30 A. M.

Chairman: Dr. Herbert B. McKean, Director of Research, Potlatch Forests, Inc., Lewiston, Idaho

Vice Chairman: Robert J. Hoyle, Jr., Assistant Director of Research, Potlatch Forests, Inc., Lewiston, Idaho

—"The Team", by John Aram, Vice President, Weyerhaeuser Timber Company, Tacoma, Wash.

—"Research Risks", by William D. McGuigan, Stanford Research Institute, Menlo Park, California.

—"Basic or Applied Research", by Dr. Howard Barlow, Director, Washington Institute of Technology, Washington State College, Wash.

—"Growth and Development", by Dr. Joseph Harrington, Jr., Arthur D. Little, Inc., Cambridge, Mass.

SESSION II New Methods and Equipment

Thursday, Sept. 10, 8:30–11:30 A. M.

Chairman: George H. Atherton, Mechanical Engineer, Oregon Forest Products Research Center, Corvallis, Oregon

Vice Chairman: B. W. Gibson, Mechanical Engineer, Longview Fibre Company, Longview, Wash.

—"A Unique Method of Proportioning Wax and Resin in Particle Board Manufacture", by John E. Balint, Vice President and General Manager, Controls & Communications Company, Eugene, Oregon.

—"The Effect of Log Loading Variables on Utilization", by J. A. McIntosh, Logging Specialist, Canadian Forest Products Laboratories, University of British Columbia, Vancouver, B. C.

—"Important Process Factors to Consider in Developing an Efficient Lumber End- and Edge-Gluing Operation", by John H. Syme, Development Director, Engineering & Development Division, Edward Hines Lumber Company, Hood River, Oregon.

—"The Development of Continuous Pulping Systems", by John O. McCutcheon, President, Argus Engineering & Development, Ltd., Vancouver, B. C.

SESSION III Management Problems

Thursday, Sept. 10, 1:30–4:30 P. M.

Chairman: Ben B. Butler, Production Manager, Western Operations, The Borden Chemical Company, Seatle, Wash.

Vice Chairman: Arthur D. Johnston, Works Manager, The Borden Chemical Company, Springfield, Oregon

—"Serendipity and Invention", by Ford E. Smith, Smith & Tuck, Patent Attorneys, Seattle, Wash.

—"Company Planning for the 1960's", by William E. Hosken, Manager of Division Development, Division of

LONGVIEW FIBRE CO. Longview plant is located on Columbia River; has 12 acres black top chip storage area.

PENNSALT of Washington Div., Tacoma, manufactures many chemicals used in pulp, paper and allied integrated operations.

Economic Research, Stanford Research Institute, Menlo Park, California.

—"Forestry Under Pressure", by M. P. Lazara, General Manager of Greenacres, Inc., Seatle, Wash.

—"People, Trees and Direction", C. Montgomery Johnson, Washington Manager of Public Affairs, Weyerhaeuser Timber Company, Tacoma, Wash.

SESSION IV Materials Handling

Thursday, Sept. 10, 1:30–4:30 P. M.

Chairman: Carl A. Rasmussen, Director of Research, Western Pine Association, Portland, Oregon

Vice Chairman: James C. Anderson, Industrial Engineer, Western Pine Association, Portland, Oregon.

—"Inflatable Dunnage for Plywood Shipments", by Ralph C. Schrouder, Production Specialist, and P. H. Edblom, Industrial Engineer, United States Plywood Corporation, Eugene, Oregon.

—"Automate Your Lumber Sorting", by E. W. DeKoning, President, Irvington Machine Works, Inc., Portland, Oregon.

—"Wood Chip Transportation by Motor Vehicle", by H. E. Lovejoy, Executive Vice President, Puget Sound Freight Lines, Seattle, Wash.

—"The Use of Suction Cups for Handling Wood Products", by E. R. Schick, Vice President, The Union Tool Corporation, Warsaw, Indiana.

SESSION V Chemistry in Wood Utilization

Friday, Sept. 11, 8:30–11:30 A. M.

Chairman: Dr. R. W. Moulton, Executive Officer, Department of Chemical Engineering, University of Washington, Seattle, Wash.

Vice Chairman: R. C. Vasishth, Chemical Engineer, Reichhold Chemicals, Inc., Seattle, Wash.

—"Magnefite Pulping of Douglas Fir", by Robert M. Samuels, Senior Research Associate, Oregon Forest Products Research Center, Corvallis, Oregon.

—"Organic Chemical Products from Wood", by Lloyd E. Van Blaricom, Group Leader, Rayonier Incorporated —Olympic Research Division, Shelton, Wash.

—"Some Properties of the Cedar Phenols", by Dr. R. H. J. Creighton, Senior Chemist, Research Division, MacMillan & Bloedel Limited, Nanaimo, B. C.

—"Sawdust, Bark and Other Wood Wastes for Soil Conditioning and Mulching", by Dr. W. B. Bollen, Bacteriologist, Oregon Agricultural Experiment Station, Corvallis, Oregon and Dr. D. W. Glennie, Chief Chemist, Oregon Forest Products Research Center, Corvallis, Oregon.

SESSION VI The Commercialization of Research Results

Friday, Sept. 11, 8:30–11:30 A. M.

Chairman: William R. Francis, Process Development Supervisor, Simpson Logging Company, Shelton, Wash.

Vice Chairman: D. S. Smith, Head, Division of Technical Services, British Columbia Research Council, Vancouver, B. C.

—"Commercializing Research Results", by E. M. Williston, Manager, Wood Products Development Department, Weyerhaeuser Timber Company, Longview, Wash.

—"Proving New Laminated Wood Building Products", by Robert J. Hoyle, Jr., Assistant Director of Research, Potlatch Forests, Inc., Lewiston, Idaho

—"The Development of a Continuous Digester Feeder", by H. John Knapp, President, Grenco, Inc., Portland, Oregon.

—"The Integral Treatment of Flakeboard With Fire Retardents During Manufacture", by Wyman Williams, Technical Director, Columbia Hardboard Company, Everett, Wash.

FIELD TRIPS

Friday, Sept. 11, 1:30–4:30 P. M.

PORTLAND AREA. Field trips by bus will include visits to the following firms:

No. 1 Timber Structures, Inc., Portland, manufacturers of glued laminated structural arches, beams, stringers, etc.

No. 2 Nicolai Door Company, Portland, manufacturers of softwood doors. Dry kilns, woodworking machinery and veneer slicers will be observed.

No. 3 Stebco, Inc., Vancouver, Washington. Firm has round log gang sawmill for cutting Douglas fir, white fir and hemlock, and chips residues for pulp market.

No. 4 American–Marietta Company, Portland. Plant makes urea resin and soya bean adhesives for use in the plywood industry.

No. 5 Pennsalt of Washington Division, Pennsalt Chemicals Corporation, Portland, Oregon. Pennsalt manufactures many chemicals, some of which are as follows: sodium chlorate, potassium chlorate, chlorine, ammonium perchlorate, caustic soda, ammonia, and cleaning compounds.

Friday, Sept. 11, 12:00–6:00 P. M.

LONGVIEW, WASH. The group will travel to Longview by bus where lunch will be served at the Weyerhaeuser Timber Company cafeteria. After lunch, selection of tours may be made for visits to the following operations:

No. 1 Weyerhaeuser Timber Company: Plywood Department; Lumber Department; Pulp Mill; Laminating Department; End and Edge Glue Department.

No. 2 International Paper Co., Long-Bell Division: Flakeboard Plant; Kitchen Cabinet Factory; Super Microseal Process.

No. 3 Longview Fibre Company: Pulp and paper mills, including continuous cooker and pneumatic chip handling; Converting Operations.

No. 4 Reynolds Metals Company, Reynolds' Longview operations consist of a Soderberg anode type of plant for the reduction of aluminum. Annual

AMERICAN–MARIETTA CO., Portland, new quality control laboratory.

SUPER-MICROSEAL equipment at Long-Bell for processing panels and cabinets.

SECTIONS in the NEWS

(Continued)

production is 60,000 tons. Rectifiers, anode preparation plant, and other auxiliary equipment required for plant operation will be observed.

SESSION VII Meeting Summation

Saturday, Sept. 12, 9:00–11:30 A. M.

This session will be held in the new Forest Products Pavilion at the site of the Oregon Centennial Exposition. The building features a sweeping seven-section hyperbolic paraboloid wood roof and will house many exhibits of the forest products of Oregon.

Chairman: Walter C. Ring, Research Engineer, International Paper Company, Long-Bell Division, Longview, Wash.

Vice Chairman: R. W. Pettersen, Technical Director, St. Paul & Tacoma Lumber Company, Division of St. Regis Paper Company, Tacoma, Wash.

—"Utilization of Manpower", by L. B. Hoelscher, Assistant Training Administrator Weyerhaeuser Timber Company, Tacoma, Wash.

—"Wood Constructed Hyperbolic Paraboloids", by James G. Pierson, Structural Engineer, Portland, Oregon, and John W. Storrs, Architect, Portland, Oregon.

—Summarization period.

Representing ASME: Mr. Conant Dodge, Chief Design Engineer, Central Engineering Department, Weyerhaeueser Timber Company, Tacoma, Wash.

Representing FPRS: Mr. John B. Grantham, Chief, Forest Utilization Research Division, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Representing AICh: Dr. Joseph L. McCarthy, Dean, Graduate School, University of Washington, Seattle, Wash.

FPRS–U. OF WISCONSIN ADHESIVES MEETING

Engineering institutes in cooperation with the glues and gluing division of Forest Products Research Society and the Forest Products Laboratory announces that its institute "Industrial Adhesives Applications" will take place on Thursday and Friday, October 1 and 2, 1959.

Companies using or considering using adhesives in the bonding of wood, metal or plastic will find in this institute solutions to problems encountered in design and fabrication with adhesives, trouble shooting adhesive bonds, and future uses for adhesives to improve product quality or reduce product costs.

Outstanding speakers from industry and the Forest Products Laboratory will present the most progressive and important views on industrial adhesives applications.

The meeting will be held in the new Wisconsin Center building on the main campus of the University of Wisconsin. This beautiful new building was created specifically for adult education programs and is admirably suited for an institute of this nature.

Further information may be obtained by writing Richard A. McCormick, 4016 Stadium, The University of Wisconsin, Madison 6, Wisconsin.

Great Lakes Section to Meet Oct. 6 and 7

"Merchandising of Lumber and Wood Products," a program jointly developed between FPRS Great Lakes Section, and FPRS National Merchandising Division, under the chairmanship of Wm. B. Lloyd, Michigan State University, will be presented Oct. 6 and 7 at the Fort Shelby Hotel, Detroit, Michigan. Registration will begin at 8:00 a.m., Tuesday.

PROGRAM, Tuesday, Oct. 6

Chairman—S. W. Tamminga, Vice Pres., Hekman Furniture Co., Grand Rapids

9:30 a.m.—Welcome—Dr. E. S. Harrar, Pres., Forest Products Research Society

9:45 a.m.—"The NLMA National Wood Promotion Campaign—B. C. Hartung, Director of Member Relations National Lumber Mfgs. Assoc., Washington, D. C.

10:30 a.m.—"That Material—Wood—Let's Merchandise it"—Speaker Pending

12:30 p.m.—Luncheon
Chairman—Everett Ellis, Assoc. Prof., Wood Technology, University of Mich.

1:30 p.m.—"Prefabrication—The Retailers Secret Weapon"—Louis E. Legg, Jr., Pres. Lansing Lumber Company, Lansing, Michigan

2:45 p.m.—"The Wood Window! On the Rebound"—Ralph Pauley, President Dayton-Akron Sash & Door Company, Dayton, Ohio

4:00 p.m.—"The Wood School! At Last"—Dr. John L. Hill, Technical Promotion, NLMA.

7:00 p.m.—Paul Bunyan Nite

PROGRAM, Wednesday, October 7

Chairman—H. Garland, Director, Forest Products Research Division Michigan College of Mining & Technology

9:30 a.m.—"The Laminated Beam Boom"—Elon E. Ellis, Vice President, Timber Structures, Inc. Portland, Oregon

10:15 a.m.—"The Madam Asks for Wood Kitchen Cabinets"—National Institute of Wood Kitchen Cabinets, Chicago, Illinois

11:00 a.m.—"The Lumberman Behind the Metal Desk"—Speaker Pending

12:30 p.m.—Luncheon
Chairman—Jack D. Skriden, Metropolitan Lumber Co., Royal Oak, Michigan

1:45 p.m.—"Wood that doesn't Burn"—S. W. Anthony, Koppers Co., Pittsburgh, Pa.

3:00 p.m.—Panel—Moderator—Wm. B. Lloyd, Assoc. Prof., Michigan State University "Where are We (the lumber industry) Going?" Panelists: Retailer; Wholesaler; Millwork Jobber; Residential Builder; Lumber Manufacturer; Architect.

Upper Mississippi Valley Section To Meet September 4

Date: Friday, September 4, 1959, from 1:00 P. M. to 9:00 P. M. at Marshfield, Wisconsin

Theme: "The manufacture and use of hardwood plywood"

Program

Guided Plant Tours: From 1:00 P. M. to 5:00 P. M. at the Roddis Plywood Corp. and the ROLLOHOME MOBILE HOMES CORP.

Paul Bunyan Hour: 5:00 P. M. to 6:00 P. M.—fellowship and relaxation

Dinner: 6:00 P. M. to 7:00 P. M.—an excellent smorgasbord

Panel Discussion: 7:00 P. M. to 9:00 P. M.—a discussion, led by a panel of experts from industry, of production problems, gluing, finishing, and marketing

Come to Texas, Oct. 11, 12 and 13

Plans for FPRS Mid-South Section's 11th Annual Meeting, to be held at the Ridgewood Motor Hotel, Beaumont, Texas, Oct. 11, 12, 13, are well-underway according to Section Secretary, Paul Kramer, Texas Forest Service.

A "Welcome to Texas" party is scheduled for Sunday evening; a full day of technical sessions Monday, and several outstanding plant tours on Tuesday morning.

Wood utilization plants to be toured include: the Kirby sawmill at Silsbee; and the new East Texas Pulp and Paper Co. at Evadale.

Ohio Valley Section to Meet Oct. 8, 9 in Chillicothe, O.

The Ohio Valley Section fall meeting will be held at the Elks Club on Thursday P.M., October 8 and at the Recreation Hall, Federal Reformatory, Chillicothe, Ohio, Friday P.M., October 9.

Program:

"New Developments in Machine Sanding" moderated by Henry Espel, Baldwin Piano Co.

"New Wood Finishes. What are the Latest Developments in Poly Vinyl, Poly Ester and other new Finishes?" moderated by Sterling Durst, Gamble Bros.

Report on N.A.F.M. Tour of European wood working plants. European methods, equipment and material utilization. Paul Fenn, chairman, and other speakers from tour personnel.

"Future of Hardwoods" moderated by Dr. Carl Trinkle. Dr. E. S. Harrar, National President of FPRS is hoped to be the speaker.

THE JOINT MEETING between the Eastern Canadian and Northeast Sections, held at Ottawa, May 25 and 26, witnessed the election of new officers. Above, new Eastern Canadian Board, l. to r., Dr. R. M. Dorland, Abitibi Power & Paper; J. A. Doyle, Treasurer, FPL of Canada; P. R. Le Sage, Arch. & Const. Specialties; E. L. Fowler, Sec., B. C. Plywood Mfrs. Assoc.; C. Allgeier, Vice-Chairman, Dominion Electrohome Ltd.; R. F. DeGrace, Chairman, Can. Inst. of Timber Construction; G. S. Bilington, Past Chmn.; Moore Dry Kiln Co.; and D. K. Saunders, international Vice-President, Westbrook, Maine.

At right, new Northeast Board, seated: Dr. E. A. Anderson, Past Chmn., N. Y. State College Forestry; J. A. Hauter, Chairman, Allen Products Co.; Don Pierce, Sec.-Treas., Farmington, Me. Standing: W. V. Fichtel, Union National Inc.; R. C. Gill, Peter Cooper Corp.; Frank Parrish, Heywood Wakefield Co.; and D. K. Saunders.

PAST AND PRESENT International Executive Boards of FPRS taken at recent Annual Meeting. Standing: Dr. F. E. Dickinson; Don Saunders; Dr. Frank Kaufert; Walton Smith; Secretary, Frank Rovsek. Seated: Joe Allegretti; Dr. E. S. Harrar; W. Jeter Eason; R. W. Warner; Jim Love; and Ray Berry.

New FPRS International Executive Board Installed at San Francisco Meeting

The results of the balloting were announced during the business session, June 29. Automatically succeeding W. J. Eason as the society's president is Dr. E. S. Harrar, Duke University. Mr. Eason remains on the Board as Past-President. Elected President-Elect is Raymond W. Berry, Scott Lumber Co., Burney, California. Elected Vice-President was W. L. Irwin, Poinsett Lumber Co., Pickens, S.C. Mr. Irwin found it necessary, because of his business, to resign the post; and Don Saunders, of Saunders Bros., Westbrook Maine was appointed by the Executive Board to fill Mr. Irwin's unexpired term of one-year.

New Regional Board members elected include: Walton R. Smith, of the U.S. Forest Service, Asheville, N.C., Southeast Regional Board Member; and James L. Love, Love Wood Products Co., Diboll, Texas, South-Central Board Member. Col. John H. Jenkins, Chief, Forest Products Laboratories of Canada was appointed Northeast Regional Board Member for the forthcoming year.

The Board noted, with recognition for their many years of service to FPRS the outgoing officers and Board members: Dr. Kaufert, U. of Minnesota; W. L. Irwin; and Dick Warner, Potlatch–Southern Lumber Co.

EMPLOYMENT *Opportunities*

Employment Wanted

556—BS grad. in wood utilization from Penn. State U., interested in furniture production, finishing, seasoning, and packaging, possibly selling.

557—Wood products engineer, BS and MS from State U. of N. Y., Syracuse, desires position in management, product development, or technical service. Presently on staff of university, avail. Oct.–Nov.

558—LSU grad. with BS in forestry, utilization option, desires work in production or preservation.

559—Jr. economic analyst seeking opportunity with integrated products firm that potentially will lead to position as forest economist and/or operations and planning analyst. Will relocate anywhere. Has unique combination of both experience and education in economics, forestry, and engineering.

560—BS grad. in wood utilization desires position in research, development, or production.

561—Assistant to research director. Available September due to laboratory closing. Experienced, training (MF) totals 17 years including R & D, admin., sales. Objective top management. Age 39, will relocate, resume on request.

562—Graduate of N.Y. State College of Forestry with BS in wood products engineering field available for employment July 1959. Majored in wood utilization with courses in production management, finishing and personnel relations. Experience in wood products industries.

563—Single, 30 yrs. old. Desires job as wood research or for. ind. economics research or planning or administration, also education. A.B. degree from Cornell Univ. in Economics and M.F. from Yale in Management with heavy mixture of wood tech. & Fur. Prod. courses. Exp.

564—Public relation liaison contact man. Sales. Married, 48 yrs. old. Education and past experience are in the field of sound and production in radio and T. V. field.

566—Mich. State Univ., Wood Technology graduate, with a masters degree, desires a position in product development or as technical representative. Have had one year of experience in a plywood research laboratory.

567—Will receive B.S. in Wood Technology in August 1959 from Univ. of Mich. 27 yrs. old, married and two children. Veteran. Desires employment in production or sales, involving primary or secondary mfg. Available Oct. 1959 and prefers Northeastern states.

568—Executive, age 40, desires position as director of structural laboratory. Successful experience developing, planning and supervising research work in the general field of structural laminates. Presently doing research and development with large plywood corporation.

Positions Offered

E-353—Position available for outstanding man who has ability to advance. Large, integrated progressive store-fixture plant. Midwest location. Send resume.

E 356—New position being created by multi-plant pressure treating company. Responsible for directing and improving treating techniques, maintaining quality of products and for liaison with all sources of technical information. Qualifications include a degree in wood technology or chemistry and at least ten years experience in the treating industry. Salary commensurate with these qualifications.

E 357—Full-time research position to develop a research program in wood technology and products at Midwest forestry school. Ph.D. required. Properly qualified person to be appointed at professor grade.

Stacking is but one of the several jobs handled by fork-lift trucks.

When the stack is finished, a protective roof is easily put in place.

Small Mill Lumber Handling[1]

MECHANIZATION IN THE AVERAGE sawmill throughout the Central States is sorely needed. One of the major methods of reducing costs in the sawmill today is in developing good and efficient lumber-handling techniques. It is here that poor methods lead to high turnover in sawmill management.

The average operator concentrates on the uniform thickness and grade of his lumber, but gives no thought to the concept that a properly manufactured board aids materially in lumber handling. It is important when one bears in mind that the average board will be handled five times before the consumer puts the saw to it.

There are sawmill operators who are held back by custom but will give an ear to practical suggestions. It is to this group that these comments are directed. By spotlighting areas for improvement, it is hoped that the lumber industry will be assisted in reducing waste, which in turn reduces costs. Each bit helps in keeping lumber competitive with other products, whereby a constant demand is created.

Let us take a look at the average sawmill in the Central States. Why take a look at it? Back in 1953,[2] 96 percent of the sawmills in Illinois and Indiana cut less than one million board feet per year, and yet these same mills combined accounted for 80 percent of the lumber cut that year in the two states. Should this same percentage apply throughout the Central States, one is speaking of better than 10,000 sawmills.[3]

This average mill is a ground mill with a circular saw belt driven by a gasoline engine that runs a 16-foot carriage with a 40-inch headblock opening. An edger and a swing cut-off saw round out the general sawmill equipment. In the yard, however, is a winch truck used principally for logs and handling solid-stacked lumber. The equipment is operated by a five-man crew broken down to a sawyer, edgerman, edger off-bearer and trimmerman, off-bearer, and winch-truck operator. This mill will cut 3 to 4 thousand board feet per day, and will saw approximately 150 days per year. Production is low per man because the crew is either stacking lumber or is idle when the sawyer takes time out to file or talk to a visitor.

This average mill can be helped by mechanization, but the usual management is not receptive to outside assistance. These mills appear on the horizon and fade away with economic changes, leaving a small minority to develop into larger and more permanent enterprises.

The more progressive operator has switched from gas to diesel or electric power. His other equipment has not changed, but he has added manpower. This operator will have a deck hand to assist the sawyer, and will have added two men to stack lumber at minimum wages or a given rate per thousand board feet. Usually the lumber is solid stacked behind the mill in 500- to 600-board-foot bundles. It is then carried to the yard with a winch truck, the bundle dangling at the end of the cable. Two men are required to set it down properly so the cable can be released. There has been no sorting per grade, but the percent of number two common and poorer has been reduced by cutting the hearts into industrial blocking or farm lumber.

This operation goes quite smoothly until a shipment is made. Then the stackers can not keep up, because they are needed to assist the lumber inspec-

NELS GLESNE

President, Casswood Industries, Inc., Beardstown, Ill.

The average (small) sawmill could wisely invest $14,000 for a 4-wheel-drive hydraulic fork lift truck in the 10,000–12,000 pound capacity range.

[1] Presented at Session XIV, Lumber Manufacturing, FPRS 12th National Meeting, June 26–27, 1958, Madison, Wis.

The Author: Nels Glesne holds a BA from Olaf College, and a BS from Iowa State. He joined Casswood in 1951 after holding several private and state forestry positions.

[2] Small Sawmills in Farm-Industrial Areas of Indiana and Illinois, Station Bulletin 585, January 1953, Purdue University, Agricultural Experiment Station, Lafayette, Indiana in cooperation with the University of Illinois, Agricultural Experiment Station, Urbana.

[3] Facts about Forests of the Central States, 1952–53 Edition, American Forest Products Industries, Inc., 1319 Eighteenth Street N. W., Washington 6, D. C.

tor. Meanwhile green lumber is building up at the mill. If stacking gets too far behind, the mill is shut down, and again all available hands not needed for repair or touching up saws are used.

Perhaps during one of those moments when the market is up, the mill is down, and the crew has quit and gone to town, the sawmill operator will sit back and take a look at his enterprise. Suddenly the realization of the sawmill proverb will strike him: "When the saw isn't buried in a log, you are loosing money." With this awakening comes a readjustment of personnel and elimination of bottlenecks to gear his operation to his business venture.

During this review of his business, this better-than-average operator will find that he can get a unit to handle his logs and lumber. He can stick his lumber behind the mill. By so doing he can release his winch truck to his loggers and let one of his yard men go. In addition to the man replaced by the machine, the operator will find that his cost of handling can go down, because he will be able to grade his lumber at point of loading and thus eliminate another handling.

If the operator is an average one, he has an area too small for his now-growing yard needs. He cannot go anywhere but up, and finds that with the proper unit he can increase the capacity of his yard by 20 to 25 percent. By being able to handle lumber in and out of his yard more efficiently, it is discovered that the mill will have more time to saw lumber, which means increased production. The safety of the workers will be increased immensely by the switch away from a winch truck.

What is this one unit that can do so much? There are a number on the market ranging in price from $5,500 on up to $22,000. Basically, the machine is a four-wheel-drive, rubber-tired machine with hydraulically operated forks. A 6,000-pound unit is the absolute minimum and would not be very efficient for this operation. The most efficient one for the dollars spent probably is a 10,000- to 12,000-pound-capacity machine. Other things to look for are turning radius, tilt of the forks (enough to permit self dropping of logs off the forks), and an arm for holding logs on the forks.

How much can the sawmill operator spend for this unit? He can spend up to $14,000 and be making a wise investment, on the basis of what one man costs per year.

Angular positioning of stacks facilitates maneuvering for the fork-lift trucks at Casswood.

The average man is going to cost a sawmiller in this area $4,000 to $5,000 when the burden rate of taxes, insurance, and so on, is applied to his wages. If, with $5,000, a manager can replace a laborer, he is a fool to sit around and not do something about it. If, with $10,000, a worker can be replaced by a machine it is a sound investment and worth going out to borrow some working capital. If it takes $15,000 to replace one man, it is not out of the question but with tight money it bears close investigation. These are personal thoughts that have been successful guides in the casswood operation at Beardstown, Illinois.

Thus, with a sound investment, many a sawmiller can improve his operation so as to ship better air-dried lumber at reduced costs. Though there is always room for improvement in any stage of logging and sawmilling the Central States sawmills can most probably make their greatest improvement in the stages of handling the lumber after it drops from the head saw. An investment of $6,000 to $14,000 seems necessary and justifiable for the normal sawmill operator in this area. Yet, an $18,000 investment is within the realms of good judgment for the purchase of a multi-purpose machine to feed the mill with logs and handle and load out lumber more efficiently.

Discussion

J. W. Young: How have your handling costs been affected by the use of the lift truck?

Mr. Glesne: Before we used the lift truck, our yard handling costs averaged $4.60 per M. The lift truck has lowered these costs by 48 percent, to $2.39 per M.

Gregory Baker (U. of Maine): Do you have preset foundations in your yard?

Mr. Glesne: Yes, we do, and with stickers aligned on only one side, even inexperienced can do a good job.

R. F. Haussman (U. S. Forest Service): What is the purpose behind the herring-bone pattern of your yard stacks?

Mr. Glesne: First of all, this means that the lift truck has to make only a 45-degree turn, instead of a full 90 degrees. Mainly, however, our experience shows that we get more uniform drying in stacks exposed to the wind on a full side, as ours are.

R. V. Vaughn (L. Vaughn Co.): You spoke of the majority of mills in the Central States (and also the West Coast) as being small mills, and that because of their size the packaging of lumber would be an added cost to the mill. If the receiver did specify packaged lumber, would he be able to obtain it from the smaller mills?

Mr. Glesne: I think so, with regard to truck loading. To handle packaged lumber in box cars, both shipper and buyer would need booms.

Mr. Vaughn: Would small mills make this type of investment, mainly for the purchaser's benefit?

Mr. Glesne: Only at the strong demand of a good customer.

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HOW WAX AND PARTICLE SHAPE AFFECT

Stability and Strength of Oak Particle Boards[1]

B. G. HEEBINK AND R. A. HANN
Forest Products Laboratory[2]
Forest Service
U. S. Department of Agriculture

Primary purpose: To determine the effect of particle shape and inclusion of wax on the dimensional changes in particle boards conditioned to constant weight at various relative humidities. Secondary objectives: To consider the effect of different particle shapes on strength properties, and to learn about the amount of fines produced.

Results: Boards made with 1-inch-long flakes were the strongest in all respects and the most stable linearly. Other boards, in order of strength, were of ¼-inch-long flakes, planer shavings, slivers, fines, and sawdust.

THE PARTICLE BOARD INDUSTRY, which offers an efficient method of converting woods and mill waste into a marketable product, has grown rapidly in recent years. Technical knowledge regarding the properties and potential uses of particle boards has not kept up with the rapid growth in productive capacity.

One of the greatest needs of the industry today is basic information on physical and mechanical properties as related to manufacturing variables. Such information would permit the manufacturer to aim at specific markets and aid the consumer in purchasing the correct product for his uses. This investigation is one of several planned by the Forest Products Laboratory to furnish part of this basic information.

Six types of particles were produced from northern red oak: 1-inch-long flakes, ¼-inch-long flakes, planer shavings, slivers, sawdust, and fines (from screening the slivers). Three ½-inch-thick particle boards were prepared from each of the six particle types, using 8 percent urea-resin binder. Three additional boards, which contained 1 percent wax in addition to the 8 percent urea resin, were prepared from the first four of the particle types.

[1] Prepared for presentation at the June 1959 National Meeting of the Forest Products Research Society at San Francisco.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

Fabrication Procedure

Log Breakdown: The material was obtained from a log of northern red oak (*Quercus rubra*) 8 feet long, 25 inches in diameter at the butt end, and 21 inches in diameter at the top. The specific gravity, based on weight when ovendry and volume when green, was 0.56 ± .05. The material had an average of 12 annual rings per inch with a range from 9 to 16. The log was sawed while green, and the resulting 2-inch planks, sawdust, and slabs were stored at 36° F. and 80 percent relative humidity to prevent excessive drying before they were further processed.

Particle Preparation: Sawdust from the log breakdown was dried on trays in a large oven to an average moisture content of 6 percent. This dried sawdust was then screened through a 14- by 18-mesh rotary screen. The retained fraction was used to make the "sawdust" boards.

Slabs from the log were barked by hand and run through a pulpwood chipper with knives set for a ½-inch chip length. The chips were then hammermilled through a ¼-inch screen, dried to 6 percent average moisture content, and screened in the 14- by 18-mesh rotary screen. The hammermilled particles retained on the rotary screen were used to fabricate the "sliver" boards.

Fines that resulted from screening the slivers were used to make "fines" boards.

Planer shavings came from several randomly selected 2-inch planks that were passed through a 2-knife, 4-inch-diameter squarehead planer, which was set to give a 1/16-inch-deep cut. The planer head speed was 3,500 revolutions per minute and the feed was 34 feet per minute. The shavings were then dried to an average moisture content of 6 percent and screened in the 14- by 18-mesh rotary screen to remove fines. The shavings retained on the screen were quite large and uniform.

Flakes were manufactured from 2-inch-thick blocks on a specially designed flaker. The knives were set to cut 0.015-inch-thick flakes, and lengths of 1 inch and ¼ inch were obtained by varying the position of spur cutters. After the flakes were screened, they varied in width because they often broke along the springwood vessels. Each of the two lengths of flakes was dried and screened separately.

Typical particles of each of the six types are shown in figures 1 to 6, and the flaker is shown in figure 7.

Veneer and Plywood Preparation

In order to compare the dimensional stability of the various types of particle board with the stability of

The Authors: Bruce G. Heebink is a University of Wisconsin graduate in mechanical engineering. He has been with the U. S. Forest Products Laboratory at Madison since 1934. Robert A. Hann received his BS and Master of Wood Technicology degrees from the University of Michigan. Since August, 1957, he has been employed as a technologist in the Division of Timber Processing at the FPL.

Fig. 1.—One-inch-long flakes, random width, from red oak lumber.

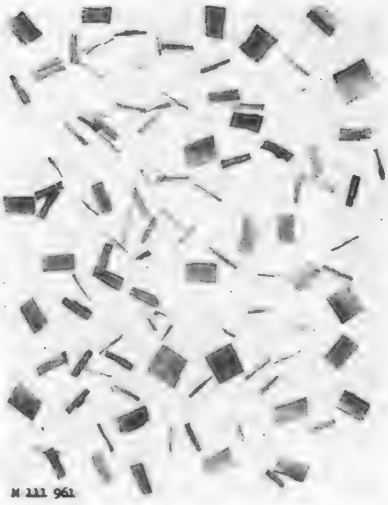

Fig. 2.—Flakes one-fourth-inch long and random width from red oak lumber.

Fig. 3.—Planer shavings from red oak boards.

matching veneer and plywood, a flitch from the same red oak log was quarter-sliced into $\frac{1}{16}$-inch veneer. This was dried at 200° F. for 25 minutes. Moisture content of this dried veneer varied between 5 and 10 percent.

Three 24- by 28-inch panels of plywood were prepared from the veneer. Eight plies of $\frac{1}{16}$-inch veneer were bonded together with a phenolic film glue at a pressure of 250 pounds per square inch and a temperature of 325° F. in a 15-minute press cycle. The grain of the two center plies was parallel to provide a construction with a 50–50 grain distribution in length and width. The three plywood panels and the remaining veneer were then allowed to condition at 30 percent relative humidity and 80° F.

Board Fabrication

Binder and wax application: Eight percent urea-resin solids, based on the ovendry weight of the particles, were applied on the particles in the following manner: First, the required weight of dry particles was placed in the rotary blender and the machine started. As the blender revolved and particles tumbled, the binder (a 66 percent solids aqueous solution) was sprayed onto the particles, over a period of 15 minutes, with a paint spray gun. This raised the moisture content of the particles to about 10 percent.

One percent wax, which was added to some panels, was sprayed on the particles as an emulsion after the binder was applied.

Forming the mat: The resin-coated particles were removed from the blender, and the correct amount weighed out. Then the mat was formed in the 24- by 28-inch forming box.

The forming box, which has no top or bottom, was placed on a $\frac{1}{4}$-inch aluminum caul; the particles were poured in and carefully leveled by hand. A piece of plywood was placed inside the box on top of the mat and held down while the forming box was lifted from the caul. The plywood was then removed, $\frac{1}{2}$-inch-thick steel thickness stops were placed on the bottom caul, and the top caul was applied.

Pressing: The formed mat was loaded into a 50- by 50-inch single-opening hot press heated at 325° F., and the press was immediately closed. Sufficient pressure, usually 400 to 800 pounds per square inch, was applied so the press came down to the $\frac{1}{2}$-inch stops in approximately 1 to $1\frac{1}{2}$ minutes. The total press time was 15 minutes. The average density of the particles in the finished boards was essentially the same as that of the raw material.

When the pressing was completed, the finished board was allowed to cool (while standing on edge to prevent warp), then trimmed to 22 by 26 inches and stored under conditions of 30 percent relative humidity and 80° F. until equilibrium was reached. This usually took about 2 months.

The volume of each board was determined from average measurements of 10 lengths, 10 widths, and 30 thicknesses. The density, approximately 45 pounds per cubic foot, was computed from the volume and the weight of the board immediately after it was trimmed. The various types of board are shown in figures 8 through 13.

Loss in Fines: Fines, the small particles produced during machining, are usually excluded from board manufacture and often burned, because such particles absorb a higher amount of binder than larger particles when both are used in making boards.

In this investigation samples of particles, both green and at 6 percent moisture content, were screened by several methods. To determine the percent of fines that resulted, the weight of fines from each sample, times 100, was divided by the weight of the sample.

The type of particle, method of screening, and percent of fines produced are shown in table 1.

Method of Test

Dimensions were determined on each board in equilibrium with various humidities, as well as water resistance (under the 24-hour soak test), static bending strength, and tensile strength perpendicular to the face. Specimens were cut as shown in figure 14.

The dimensional stability tests consisted of measuring the change in thickness and length of the strips from equilibrium conditions at 30 percent relative humidity at 80° F. to equilibrium at the following conditions: Ovendry; 65 percent relative humidity at 80° F., 80 percent relative humidity at 80° F., 90 percent relative humidity at 80° F., Saturated with water at room temperature.

Five specimens ($\frac{1}{2}$ by 1 by 2 inches) from each board were measured while at equilibrium in 30 percent relative humidity at 80° F.; then one was moved to each of the above five conditions and allowed to reach equilibrium (2-month exposure) before being remeasured.

Thickness was determined by averaging five readings of a dial micrometer taken at random along the specimen.

Fig. 4.—Slivers obtained by hammermilling ½-inch chips through a hammermill plate with ¼-inch holes.

Fig. 5.—Fines that result from screening slivers.

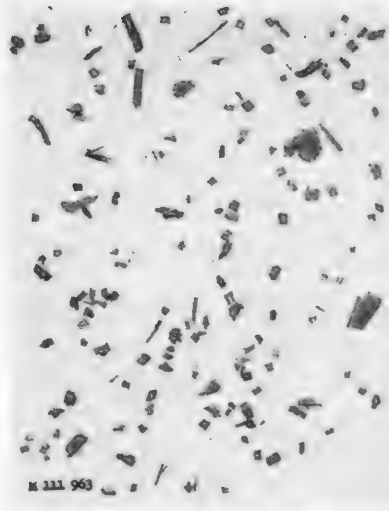

Fig. 6.—Particles used to make sawdust particle board.

Change in length was determined by measuring the distance between two small holes drilled approximately 20 inches apart in each specimen. This distance was measured by a dial micrometer on a slide that contained one fixed point and an adjustable point (fig. 15). The accuracy of both thickness and length measurements was ±0.001 inch. The weight of each strip was also taken to 0.1-gram accuracy on a torsion balance.

The 24-hour soak tests consisted of soaking 2- by 2-inch squares in water at room temperature for 24 hours. The weight to 0.01 gram, thickness at 5 places to ±0.001 inch, and length in both directions to ±0.001 inch were measured before and after soaking; then the percent increase in weight, thickness, and length was determined for each specimen.

The mechanical tests—static bending and tension perpendicular to the face—were performed in accordance with ASTM Standards on testing "Wood-base Fiber and Particle Panel Materials" (D1037–58T), except that the specimens were conditioned at 30 percent relative humidity at 80° F. instead of the 65 percent called for by the standard.

Fig. 7.—Flaker, with guard removed, that was used to manufacture 1-inch and ¼-inch flakes for the particle boards.

Results of Tests

Dimensional Stability: In length the 1inch flake boards, with and without wax, were the most stable of all the particle boards, being practically equal to the plywood; others, in order, were boards made with ¼-inch flakes, planer shavings, slivers, fines, and sawdust. These results are shown in fig. 16 and table 2.

The flake and the shaving boards, with and without wax, were the most stable in thickness, followed in order by those made from fines and slivers. The most stable particle board expanded from ovendry to soaked condition over three times as much in thickness as red oak lumber did in the tangential direction (fig. 17 and table 2).

The equilibrium moisture content of the specimens at a constant humidity appeared to be unaffected by either particle type or the addition of wax.

Water Absorption: The results of the 24-hour soak test (table 3) show that water absorption is directly related to particle type. Also, the addition of 1 percent wax to the particle board improved the water resistance as measured by the 24-hour soak test.

Mechanical Properties: The 1-inch flake boards were the strongest, both in tension perpendicular to the face and in bending. The strength of this and the other types of boards is shown in table 4. The addition of wax to all types of boards had no measurable effect on the flexural strength or the strength in tension perpendicular to the face as compared to boards made with similar types of particles and no wax. The best particle board was about half as strong in bending as plywood bent in the strong direction, but only slightly weaker than the plywood when bent in the weaker direction. Particle board and plywood were sim-

Table 1.—PARTICLE TYPES AND RESULTING FINES THAT PASS THROUGH A 14- BY 18-MESH SCREEN

Particle type[1]	Fines Percent
Fine headsaw dust (60-inch circular saw running at 540 revolutions per minute, ⅛-inch kerf, slow feed, rotary screen)	72.6
Coarse headsaw dust (At recommended feed, rotary screen)	16.4
Green hammermilled ½-inch chips (Hammermill had ¼-inch screen, rotary screen)	21.4
Green hammermilled ½-inch chips (Hammermill had ¼-inch screen, oscillating screen)	34.0
Green hammermilled ½-inch chips (Hammermill had ¼-inch screen, tilted oscillating screen)	39.4
½-inch pulp chips (Not hammermilled, rotary screen)	6.4
Planer shavings (Hammermilled green (70 percent moisture content) through ¼-inch screen, rotary screen)	24.9
Planer shavings (Hammermilled at 10 percent moisture content through ½-inch screen, rotary screen)	20.5
Planer shavings (Hammermilled at 10 percent moisture content through ¾-inch screen, rotary screen	17.5
Planer shavings (Dry, rotary screen)	8.9
¼-inch flake (No hammermill, dry, rotary screen)	7.4
¼-inch flake (Hammermilled, no screen, dry, rotary screen)	11.9
1-inch flake (Dry, no hammermill, rotary screen)	7.3

[1] Underlined particle types are used in boards.

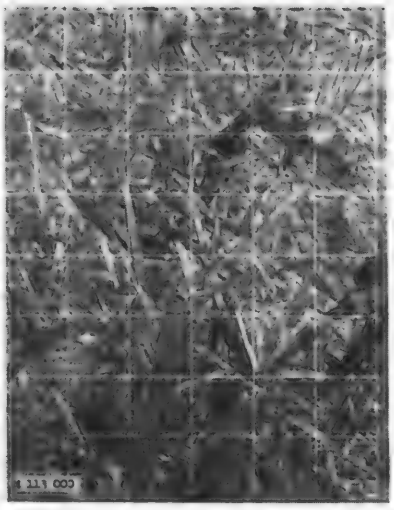

Fig. 8.—Board made from 1-inch-long flakes.

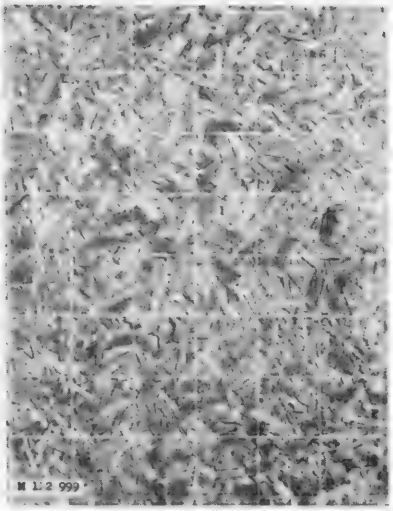

Fig. 9.—Board made from ¼-inch-long flakes.

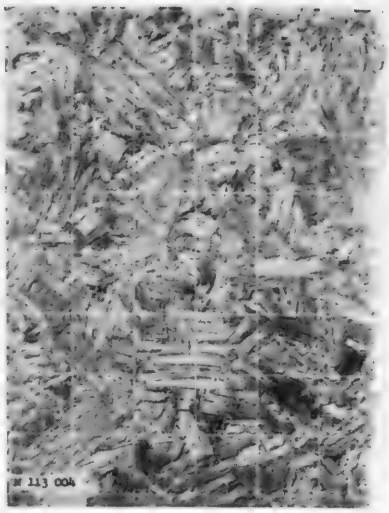

Fig. 10.—Board made from planer shavings

ilar in tension perpendicular to the face, although the particle board values varied somewhat with type of particle.

Raw Material Lost as Fines: The amount of fines produced in manufacturing various particles ranged from 7.3 percent for the 1-inch-long flake to 72.6 percent for fine sawdust (table 1). Planer shavings resulted in 8.9 percent fines and ¼-inch-long flakes gave 11.9 percent. The hammermilled slivers produced 21.4 percent fines.

Discussion

This investigation provides information on the effect of wax on the dimensional stability and strength of particle boards made from oak with a urea-resin binder. The effect of adding 1 percent wax was slight. In this respect the results were similar to those reported by Maku, Sasaki, and Hamada[3] flor flake-type particles, but Talbott and Maloney[4] report some improvement in strength properties by adding wax. This apparent disagreement is possibly caused by the difference in binder or species (Talbot and Maloney used Douglas-fir and a powdered phenolic resin) or possibly in the sequence of applying the bind and wax to the particles.

The results show that boards some types of particles are made s nificantly more stable by addition 1 percent wax, but most types boards are not improved. The reas for this selective stabilization of c tain particles (slivers) is not appare but it is important to note that board made from flakes of 1 inch and ¼ inch, shavings, fines, and sawdust e not benefited by the inclusion of 1 percent wax.

The addition of 1 percent wax to particle board lowered the rate of liquid-water absorption and the rate of dimensional change as measured in the 24-hour soak test (table 3); but,

[3] Maku, T., Sasaki, H., and Hamada, R. The Effect of Paraffin Emulsion on the Hygroscopic, Swelling and Mechanical Properties of Chipboard. Journal of Japan Research Society, Vol. 2, No. 3, (130–2) June 1956.

[4] Talbott, T. W., and Maloney, T. M. Effect of Several Production Variables on Modulus of Rupture and Internal Bond Strength of Boards Made of Green Douglas-fir Planer Shavings. Forest Products Journal, Vol. VII, No. 10, October 1957.

Table 2.--Summary[1] of average change in dimensions and weight of boards from equilibrium at 80° F. and 30 percent relative humidity to equilibrium at other conditions

Material used to fabricate boards	Change in length to					Change in thickness to					Change in weight to				
	0 percent relative humidity: 220° F.	65 percent relative humidity: 80° F.	80 percent relative humidity: 80° F.	90 percent relative humidity: 80° F.	Soak at 72° F.	0 percent relative humidity: 220° F.	65 percent relative humidity: 80° F.	80 percent relative humidity: 80° F.	90 percent relative humidity: 80° F.	Soak at 72° F.	0 percent relative humidity: 220° F.	65 percent relative humidity: 80° F.	80 percent relative humidity: 80° F.	90 percent relative humidity: 80° F.	Soak at 72° F.
Particle boards from:	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Sawdust	-0.36	0.43	0.88	1.41	2.91	-1.0	1.4	3.9	8.2	21.6	-3.6	3.5	7.3	11.5	87.1
Fines	-.26	.33	.58	.81	1.33	-1.0	1.8	5.1	11.3	27.3	-3.4	3.5	7.2	11.6	94.3
Hammermilled slivers	-.26	.28	.48	.80	1.79	-1.0	2.4	6.9	15.2	47.1	-3.3	4.3	8.0	12.7	109.3
Hammermilled slivers plus 1 percent wax	-.22	.26	.49	.68	1.51	-1.0	1.9	5.6	11.2	33.6	-3.6	3.6	7.4	12.5	88.5
Planer shavings	-.21	.26	.43	.56	1.01	-1.0	1.8	5.3	9.6	29.8	-3.3	3.6	7.3	11.8	87.8
Planer shavings plus 1 percent wax	-.23	.24	.42	.59	.95	-1.0	1.9	4.3	8.7	22.3	-3.1	3.5	7.1	11.5	77.9
1/4-inch-long flakes	-.17	.25	.38	.50	.90	-1.0	1.9	4.1	8.9	22.1	-3.2	3.7	7.3	12.5	82.2
1/4-inch-long flakes plus 1 percent wax	-.17	.25	.35	.58	.88	-.8	2.5	4.0	7.9	22.0	-3.3	3.6	7.3	11.4	74.3
1-inch-long flakes	-.15	.21	.26	.28	.38	-.8	2.3	4.6	9.4	22.7	-3.2	3.6	7.2	11.9	74.6
1-inch-long flakes plus 1 percent wax	-.16	.21	.29	.32	.41	-.8	2.1	4.8	9.6	22.5	-3.1	3.5	7.2	11.4	69.5
1/2-inch plywood	-.15	.17	.23	.34	.47	-2.2	1.4	2.4	6.7	22.9	-4.8	2.9	6.4	9.5	66.5
1/16-inch veneer	-.08	.12	.15	.24	.50					6.6	-4.6	3.3	7.3	25.8	110.4

[1] Data are based on 3 replications of each variable.

Fig. 11.—Board made from slivers.

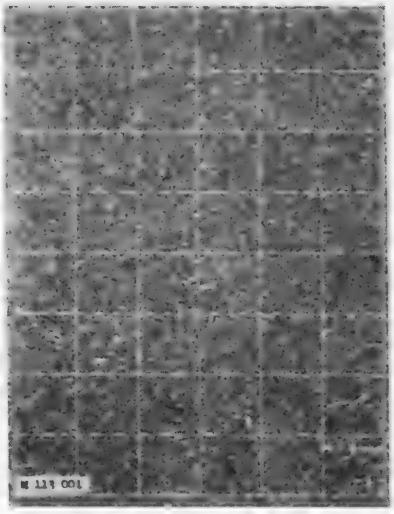

Fig. 12.—Board made from fines that result from screening slivers.

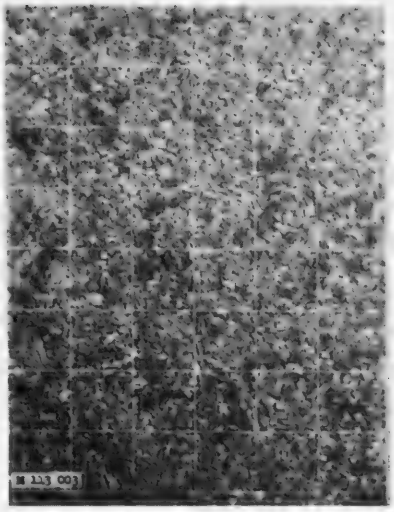

Fig. 13.—Board made from sawdust.

after two months, the strips containing wax absorbed 90 percent as much water or 95 percent as much water vapor as strips of the same particle type without wax (table 2). Since the addition of wax had no appreciable effect on the amount of water vapor absorbed after 2 months, the degree of stabilization that occurred because of the addition of wax to sliver boards might be attributed to some action other than moisture exclusion.

Very little is known about the interaction of particles and binder in board formation. Particle size is no doubt one important factor. Kitahara and Kasagi[5] showed that, with equal binder distribution per unit of surface area, small particles are superior to large particles of the same shape. They reasoned that this was because the smaller particles tend to form a more uniform board as they were pressed. However, in this work the amount of binder was based on the weight of wood. Therefore small particles, which have a relatively large amount of surface per unit of weight, would have less resin per unit of surface area. It appears then that a decrease in particle size may be either detrimental or beneficial, depending on the shape and specific conditions.

Particle shape is another important factor. Turner[6] found that long, flat flakes had the best strength properties, that shavings from a milling-type head showed only moderately good properties, and that use of small cubes (similar to the sawdust used here) resulted

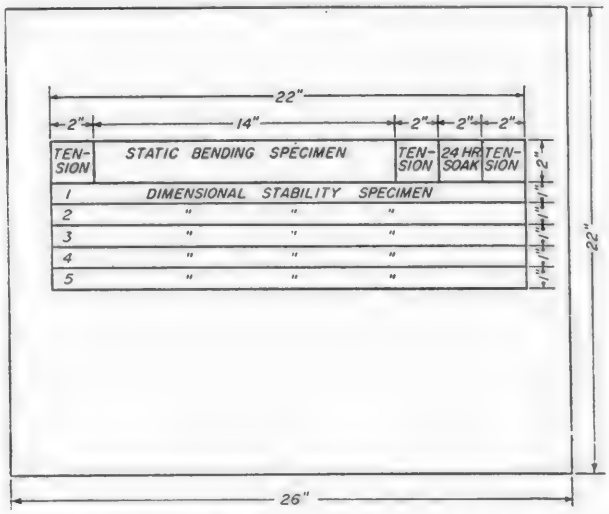

Fig. 14.—Cutting diagram showing location of specimens in test panel.

[5] Kitahara, K., and Kasagi, K. Effects of Raw Chips Dimensions on the Physical and Mechanical Properties of Chipboard. Report 113. Wood Material Section, Agriculture Dept., Tokyo Univ., October 1957.

[6] Turner, H. Dale. Effect of Particle Size and Shape on Strength and Dimensional Stability of Resin-Bonded Wood-Particle Board.

Table 3.—DIMENSIONAL INCREASE IN PARTICLE BOARD SPECIMENS AFTER 24 HOURS' SOAKING IN WATER

Particle type	Length Percent	Thickness Percent	Weight Percent
Sawdust	1.90	12.0	49
Fines	1.36	12.2	104
Slivers	1.36	21.0	75
Slivers plus 1 percent wax	.67	9.4	24
Planer shavings	.85	11.4	71
Planer shavings plus 1 percent wax	.83	6.2	24
inch-long flake	.70	11.0	54
inch-long flake plus percent wax	.62	4.7	24
inch-long flake	.70	12.4	71
inch-long flake plus percent wax	.37	4.6	19
wood	.90	7.5	32

Table 4.—RESULTS OF PARTICLE BOARD STRENGTH TESTS

Particle type	Static bending			Tension perpendicular to the face
	Modulus of rupture	Modulus of elasticity 1,000	Proportional limit	
	P.s.i.	P.s.i.	P.s.i.	P.s.i.
Sawdust	1,615	250	909	307
Fines	2,402	273	1,085	345
Slivers	2,636	353	1,433	359
Slivers plus 1 percent wax	2,514	369	1,434	341
Planer shavings	2,891	417	1,699	286
Planer shavings plus 1 percent wax	2,905	466	1,784	261
¼-inch-long flake	3,425	483	1,991	377
¼-inch-long flake plus 1 percent wax	3,426	590	1,940	361
1-inch-long flake	6,318	744	3,908	423
1-inch-long flake plus 1 percent wax	6,303	691	3,389	436
Plywood made of quarter-sliced red oak:				
Parallel to face grain	11,493	1,444	5,090	319
Across face grain	7,352	724	5,090	---
Oak lumber (parallel to grain)	15,807	1,440	10,410	---

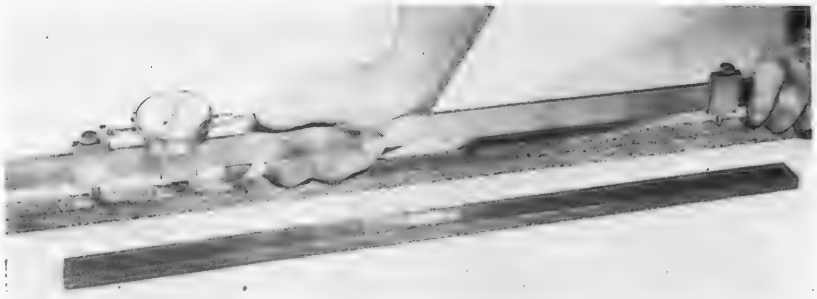

Fig. 15.—Apparatus used to measure change in length of dimensional stability specimens.

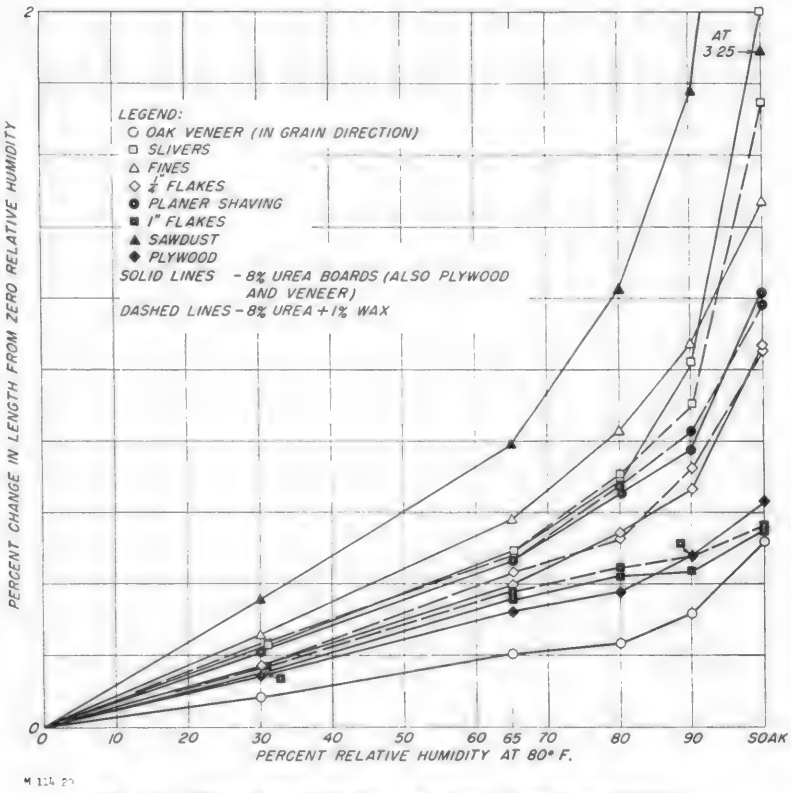

Fig. 16.—Effects of particle shape on linear dimensional stability.

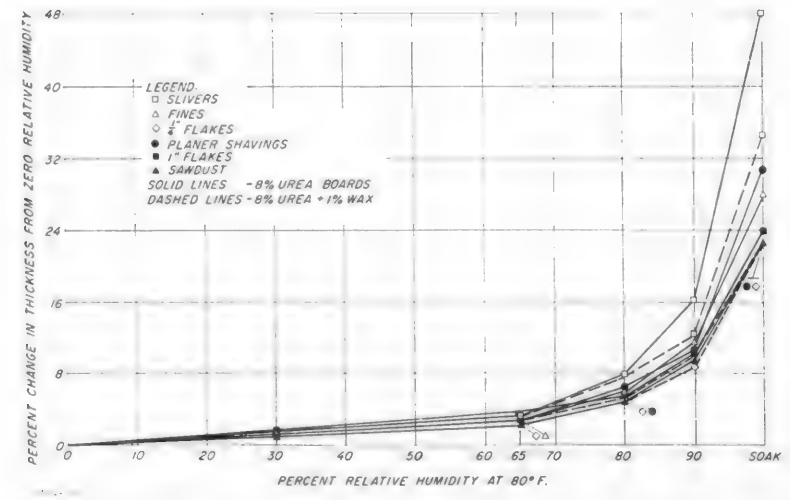

Fig. 17.—The relation of change in thickness to percent relative humidity.

in weak boards. The results given in this report verify Turner's findings in this respect. Turner also found that strength and dimensional stability were inversely related to the amount of fiber damage. Planer shavings, sawdust, slivers, and fines probably sustain more fiber damage than flakes and therefore should be weaker and less stable than boards prepared from such cleanly cut particles as flakes.

The results show the 1-inch-long flake to be the best size and shape among those used in this investigation. The ¼-inch-long flake was not as good, apparently because length is more critical than the more uniform distribution that might result from smaller flakes. The fines, planer shavings, and slivers produced boards that were quite similar in properties. They were not as good as boards made with flakes, but definitely superior to the boards made with the screened sawdust.

Another factor that has not been previously discussed here is binder efficiency. The binder is probably used most efficiently when applied between two well-prepared surfaces, with sufficient pressure to form a good bond. Anything that prevents such a bond will be detrimental to the properties of the board. Particles with large percentages of end-grain surfaces, which are usually difficult to bond, and thick or irregularly shaped particles whose sides receive little pressure would waste much of the resin applied to them. This could explain the poor properties exhibited by the sawdust board.

Unfortunately, at present the amount of fines that result from various particle machining operations is important, because fines usually are excluded and often burned. Therefore, a process that produces a high percentage of fines requires more raw material than one that produces only a small amount of fines. The percent of fines that resulted in screening the different particles used in this work varied from 7.3 to 72.6 percent. This variation is so great that, in spite of the low cost of raw material, the amount of fines produced becomes a factor in the choice of a manufacturing process.

The problem of meaningful tests is of primary importance in particle board research. In this research the 24-hour soak test and the 2-month soak test give contradicatory versions of the effect of wax on water resistance. These varying results are explained on the basis of a temporary delaying action by the wax, but they do point out the danger of misinterpreting data. Certainly the results of

4-hour soak test are not indicative of ne possible results of a 2-month soak st.

Conclusions

Test results showed that the boards ade with 1inch-long flakes were the rongest in all respects and the most ible linearly; other boards, in order strength, were from ¼-inch-long kes, planer shavings, slivers, fines, d sawdust. The addition of 1 per- nt wax to the boards had no ap- eciable effect on dimensional stabil- or on strength; however, it greatly tarded the rate of liquid water sorption.

The percent of fines (material that would pass through a 16-mesh screen) was approximately 7 percent for 1-inch-long flakes, 9 percent for shavings, 10 percent for ¼-inch-long flakes, 21 percent for slivers, and 73 percent for sawdust.

The dimensional stability of oak plywood made from the same log was only slightly better than the dimensional stability of particle board made from 1-inch-long flakes; the oak plywood was about twice as strong and stiff in the face grain direction, but 25 percent lower in tension normal to the surface.

Particle size and form were definite factors in both the strength and dimensional stability properties of particle boards. The 1-inch-long flake was the best form and size used in this investigation.

The addition of wax as applied in this work retarded water absorption temporarily, but had no permanent effect in improving dimensional stability after long exposure. Therefore, a 24-hour soak test is a poor indication of dimensional stability that may be expected under longer exposure to equilibrium conditions.

The addition of wax had no measurable effect on the strength properties of the boards tested.

The amount of fines produced varied greatly with particle type and screen action.

EFFECT OF PRESS CYCLES AND MOISTURE CONTENT ON

Properties of Douglas-Fir Flakeboard[1]

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Press cycles, moisture content, and moisture content distribution affect such physical properties of particle boards as layer density, moduli of rupture and elasticity, internal bond strength, and dimensional stability. These 3 factors also affect the penetration rate of platen heat to the board center, and rate of temperature rise in the center determines resin polymerization time and, therefore, rate of production.

WHAT THIS RESEARCH MEANS

The term particle board embodies a group of panel products with a wide range of physical properties and appearances. This diversity means that a versatile line of products is being manufactured, which is adaptable to a wide range of end uses. This versatility guarantees a bright future for the particle board industry.

This paper demonstrates that it is possible to alter the physical properties of flat-pressed particle board by manipulating press cycle and total moisture content as well as moisture distribution in the mat. This is brought about primarily by control of the density distribution through the board thickness. Thus, it is possible to enhance the versatility that the particle board industry now enjoys by adapting press cycles to different end-use specifications.

A further consideration is that moisture in the form of steam is the primary medium for conducting heat to the center of particle board during hot pressing. Although excessive moisture adversely affects board strength, its control in the board can be used to reduce pressing time and to enhance some characteristics of the board.

Editor

COMMERCIALLY PRODUCED PARTICLE BOARDS embody a wide range of physical properties that affect their utilitarian value. These physical differences are attributable to many factors. Press cycles and moisture content are two of the more important of these factors.

Press cycles, used with hydraulic hot presses, have historically been chosen by trial-and-error methods without prior knowledge of how those press cycles affect the physical properties of the boards being produced. Once it has been determined that certain cycles yield particle boards with acceptable properties, they have been used with little further thought towards variation or improvement. A further complication is that, in most commercial operations, particle boards are simply pressed to thickness stops and thereby held at a desired thickness throughout the pressing cycle with no further control of pressure. As a result of these practices, press cycles used in industry and research vary widely, with resultant wide variation in product quality and in interpretation of cause-and-effect relationships.

The moisture content of wood particles immediately prior to hot pressing also varies considerably in industrial practice. Some moisture is necessary to effect adequate bonding of the particles by the resin adhesive, while too much moisture causes excessive internal steam pressures that rupture or "blow" particle boards upon release of pressure in the hot press. Some research on the effects of moisture in particle boards has been conducted in Germany (2, 4)[2]. However, the total knowledge of the effects, actions, and reactions of moisture content in particle boards during pressing is limited. This research study was instigated and conducted for the purpose of studying the basic effects of press cycles and moisture content on the physical properties of particle board.

The experimental variables contained in this research project include: six press cycles, three moisture content levels, and three density levels. The moisture content levels were 6 percent,

[1] Presented at the Fall Meeting, Pacific Northwest Section of FPRS, Oct. 28, 1958, in Vancouver, B. C.

[2] Numbers in parentheses refer to the Literature Cited at the end of this report.

9 percent, and 12 percent; the density levels were 0.65, 0.75, and 0.85 specific gravity; and the press cycles were determined by trial and error during a trial run. With the three density levels, 18 press cycles were actually formulated. Four replications were thought to be necessary, since some variation was evident in trying to follow predetermined press cycles. Control of thickness and density had to be sacrificed in favor of following the press cycles.

It was decided also to maintain the predetermined press cycles throughout the three moisture content levels to preserve the unbiased effect of pressure, again at the expense of thickness and density control. Moisture softens and tends to plasticize wood, which makes it more compressible. It was therefore anticipated that density would vary considerably between moisture content levels. Because of this uncontrolled density variation, analysis of variance was not considered to be a valid statistical method for analyzing the total results. Analysis of covariance, on the other hand, with density as the independent variable, was deemed suitable, and was used to analyze the results of the research report in the following pages.

As noted above, there is a distinct difference between the usual research practice and industrial practice in the matter of pressing to stops. This research attempts to investigate the true effects of pressure as related primarily to time, and secondarily to moisture content throughout the entire cycle. A later project will attempt to correlate these findings with pressing techniques that involve stops.

Procedure

The raw material for this study was clear, one-inch Rocky Mountain Douglas-fir lumber. Flakes ½ inch long by 0.008 inch nominal thickness were produced on a 30-inch laboratory disc flaker. Short flakes were used to minimize edge effects, because of the small deckle box used for board forming. These short flakes were also believed to be more sensitive in revealing the effects under investigation.

The flakes were dried in a laboratory batch-drier to approximately 5 percent m.c. (moisture content.) The flakes were initially screened + 1/16 — 3/8 mesh to remove fines and to limit flake width to approximately 3/8-inch maximum. The flakes from the first screening were then processed through a blower system to break them along the natural cleavage planes of the wood grain. After this breaking to a reduced width, the flakes were rescreened. The final over-size flakes were discarded, because they were the excessively thick flakes that had been produced by the flaker. This degree of care in the preparation of the flakes was considered necessary to control as much as possible the chance variation that occurs between replicate boards.

All the flakes for the project then were piled together and thoroughly mixed manually. This further insured that uniform material was used in the various batches throughout the project.

One third of the flakes were redried to 3 percent moisture content and stored in polyethylene bags to maintain that moisture level. These 3 percent m.c. flakes were used to make boards at the 6 percent m.c. level. (The additional 3 percent moisture was added with the liquid resin.) The remainder of the original 5 percent m.c. flakes were used for the 9 percent and 12 percent m.c. boards.

Five percent urea-formaldehyde resin adhesive[3] and water were the only additives used. These additives were sprayed onto the flakes in a rotary-drum batch mixer. Enough material was sprayed with resin adhesive in each batch to make three boards—one of each density level in any one replication. The resin, slightly diluted to facilitate spraying, was applied first. The desired m.c. level then was adjusted by spraying water on the material immediately after the resin spray.

Boards were made in an electrically heated 15 by 15 inch hydraulic hot press. The platen temperature of the press was maintained at 290° F.

The boards were carefully felted by hand in a 13 by 13 inch deckle box. Aluminum caul plates 3/32 inch thick were used. The nominal board thickness was ¾ inch, but wide variation resulted because of the interaction of press cycles and moisture content as noted above.

The material felted in each board was weighed precisely. The felting weight was computed as the combined weight of the components that would yield a board of the desired final conditioned weight. (See Appendix) Resin and moisture are both expressed as a percentage of the weight of the dry wood.

Press Cycle Types: The number of possible press cycle variations is infinite. Press cycles could be classified in several different ways such as the rate at which initial pressure is applied, the time the initial pressure is maintained, or the manner in which a cycle is "breathed".

For the purpose of this study, it was decided to limit the cycles to the fast, initial-load type and the same final breathing pressure. For the purposes of comparison, one constant-pressure cycle was included. Cycle variations were designated on the basis of the time during which the maximum pressures were maintained, that is, "0" or peak pressure, "1", "2", "4", and "6" minutes at maximum pressure and "12" minutes at constant pressure. Thus the maximum pressures were varied for each density range and for each time limit at maximum pressure in order to produce boards of the same nominal thickness.

Trial Run: A trial run was conducted for the purpose of determining the press cycles to be used in the main experiment. Only the 12 percent m.c. level was used in the trial run. The danger of "blowing" boards in the main experiment was thereby precluded. At first, pressures were selected at random for each density level. These pressures were maintained until thickness was achieved. Pressures were then varied until the correct pressure for each time limit at each density level was determined.

Fig. 1 represents graphically the press cycles that were derived from this trial run. Specific press cycles will hereafter be designated as the time in minutes that maximum pressure was maintained.

Twelve minutes was selected as the over-all pressing time. It was assumed that a complete resin cure would be achieved in that time. Thus, it was intended to eliminate over-all time as a variable. However, several 6 percent and 9 percent m.c. boards were made at the end of the trial run. As anticipated, the 9 percent m.c. boards were thicker and of lower density than the 12 percent m.c. boards, and they appeared to be cured throughout. The 6 percent boards were still thicker and lower in density, and the resin in the center of the boards was definitely not cured.

From these results, it was decided to place thermocouples in the center of the boards on each of two replications: at ¼ depth by material weight on one replication, and on the surface on one replication.

It was also decided to hold all boards under pressure at least 12 minutes or 4 minutes at maximum center temperature, whichever was the longer time. It was felt that limiting all press times to 4 minutes at maximum center temperature would mean subjecting the board's surface layers to too wide a time range. Extending all press times to 16 minutes to allow 4 minutes at maximum center temperature for some of the 6 percent m.c. boards was thought to be unnecessary.

Experimental Design: The manufacture of the main-experiment boards was randomized with the exception

[3] The resin used was Amres 7500.

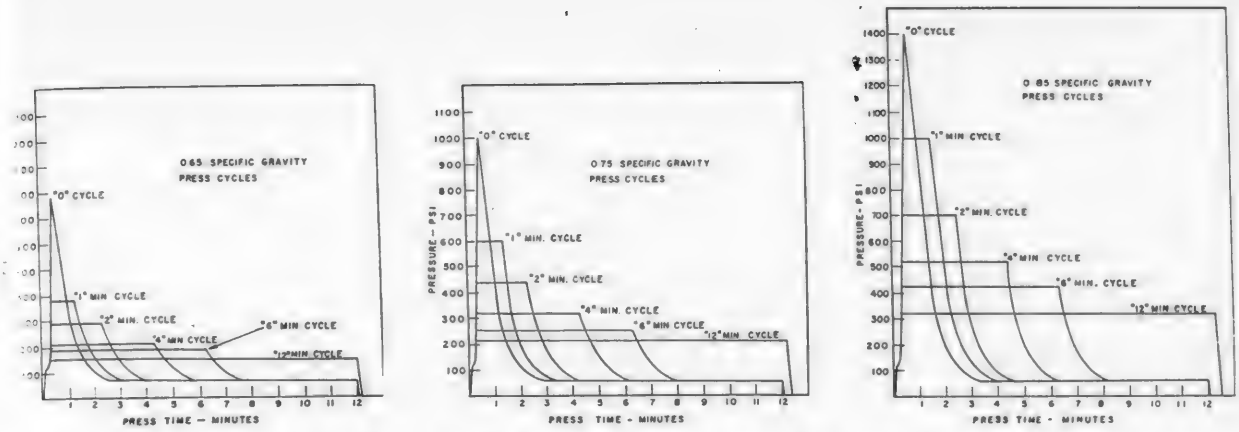

Fig. 1.—Shown above are press cycles that produce ¾-inch-thick Douglas-fir flakeboards of three density levels—0.65, 0.75, and 0.85 specific gravity—at 12 percent moisture content. Press cycle designations ("1" minute cycle, etc.) indicate minutes at maximum pressure.

that material was batch-mixed for three boards (one for each density) at a given m.c. level, press cycle, and replication. The factors of press cycle, moisture content, and replication were thus completely randomized. The density factor was also randomized within each batch. It was felt, therefore, that complete randomization was obtained.

Heat transmission results from the main experiment conclusively proved that moisture content affects heat penetration significantly. It was decided, therefore, to perform a supplementary experiment with moisture content distribution as a variable. The over-all moisture content of all boards in the supplementary experiment was 12 percent. Board centers were divided into three zones (center half, center 2/3, and center ¾) by weight of oven-dry wood. The center m.c. was divided into two levels at 6 percent and 9 percent m.c. The surface m.c. was then adjusted so that the over-all m.c. was 12 percent, as follows:

center ½	9% m.c.	surface ½ (¼ each) 15% m.c
center ⅔	9% m.c.	surface ⅓ (⅙ each) 18% m.c
center ¾	9% m.c.	surface ¼ (⅛ each) 21% m.c
center ½	6% m.c.	surface ½ (¼ each) 18% m.c
center ⅔	6% m.c.	surface ⅓ (⅙ each) 24% m.c
center ¾	6% m.c.	surface ¼ (⅛ each) 30% m.c

The three density levels of the original experiment were maintained, but only two replications were made. Also, only two press cycles were used, "2" and "12" minutes. Thermocouples were placed in the center of the boards on one replication and at quarter depth on one. One board with 30 percent surface m.c. was made with a thermocouple on the surface.

Test Specimen Preparation and Conditioning: After the boards were made, they were sawn into test specimens. Two static bending specimens ½ by 12 inches were sawn from each board. These were taken from opposite edges. One layer-density specimen ½ by 12 inches was sawn from the middle portion of each board. One water-soak specimen 3 by 8 inches and one internal-bond specimen 2 by 2 inches were obtained from the remainder of each board. All saw cuts were made with a carbide-tipped saw to insure smooth edges. Special care was used to insure precise dimensions.

All test specimens were conditioned at least two weeks in a controlled atmosphere of 70°F and 50 percent relative humidity. The resulting equilibrium moisture content was between 8 and 9 percent.

Testing Procedures: Layer-density test specimens were 1½ inches wide and 12 inches long. After these specimens were conditioned, they were weighed to the nearest tenth of a gram and the center thickness measured to the nearest thousandth of an inch. A layer nominally 0.050 inch thick was removed from one surface of each specimen with a table jointer. The specimens were again weighed and measured. The density of the surface layer removed by the jointer was then computed on the basis of the differences between the two sets of weights and measurements.

The specimens were then separated into five groups according to thickness. Three additional layers (all the same depth for any one group) were removed from the same side of the specimens so that the last layer removed straddled the specimen center line. The layer-density computations were performed for each layer in the same manner as for the initial surface layer.

Modulus of rupture, modulus of elasticity, and tensile strength perpendicular to the surface (internal bond) were determined by testing the specimens on a Rhiele universal tester according to ASTM standard designation D1037–55 T. The static bending span was reduced to 10 inches. The crosshead speed was 0.13 inch per minute. The tension perpendicular head speed was 0.06 inch per minute. Specific gravity values of the specimens were determined before they were tested.

Water-soak test specimens were weighed to the nearest 0.1 gram and measured in length and thickness to the nearest .001 inch before they were submerged. The specimens were submerged on edge in water maintained at 70°F. The water cover was one inch above the top of the specimens. At the end of two hours they were removed from the water, allowed to drain, and wiped with paper towels. Then they were weighed and measured again. The specimens were again submerged for an additional 22 hours, after which the process of draining, wiping, weighing, and measuring was repeated.

The percentage of water absorption, based on the conditioned specimen weight, was calculated for the 2- and 24-hour soak. Linear expansion and thickness swell values were also calculated for the 2- and 24-hour soak tests as the percent of dimensional increase over the original measurements.

Test Results and Discussion

Heat Penetration Study: The study of heat transmission into flakeboards during hot pressing revealed that pressure, moisture content, and moisture distribution all affect the rate of heat penetration. Fig. 2 shows the rate of initial temperature rise in the center of boards made with six press cycles at three density levels and three moisture content levels. These curves were not extended beyond the initial temperature rise because individual curves were somewhat erratic. This erratic temperature behavior after the initial rise was thought to have two causes. One, it is virtually impossible to place thermo-couple wires in the exact center of the mat of each board, and the thickness of a few flakes off the center line could influence temperature somewhat. Two, it is well known that flakes in particle board mats are never per-

fectly distributed, and high and low density areas occur throughout a board. This, too, probably causes some fluctuation in temperature along the center line of the board.

Fig. 3 shows the complete curves of temperature rise on the surface, at ¼ depth, and in the center of one board during the time required for the center temperature to equal platen temperature. Although temperature curves were erratic *after* the initial rise, two definite trends were established: 1) the maximum temperature achieved by the initial rise was governed by moisture content and was controlled thereafter by moisture content, and; 2) temperature tended to dip after the initial-rise maximum.

The rate of temperature rise on the surface of the boards did not vary with changes in moisture content or pressure. Contact between hot platens and cold particle board assembly cooled the platens at the beginning of the press cycle. The platens soon regained normal temperature, however, irrespective of moisture content or platen pressure.

The initial rate of temperature rise at ¼ depth in the particle boards was

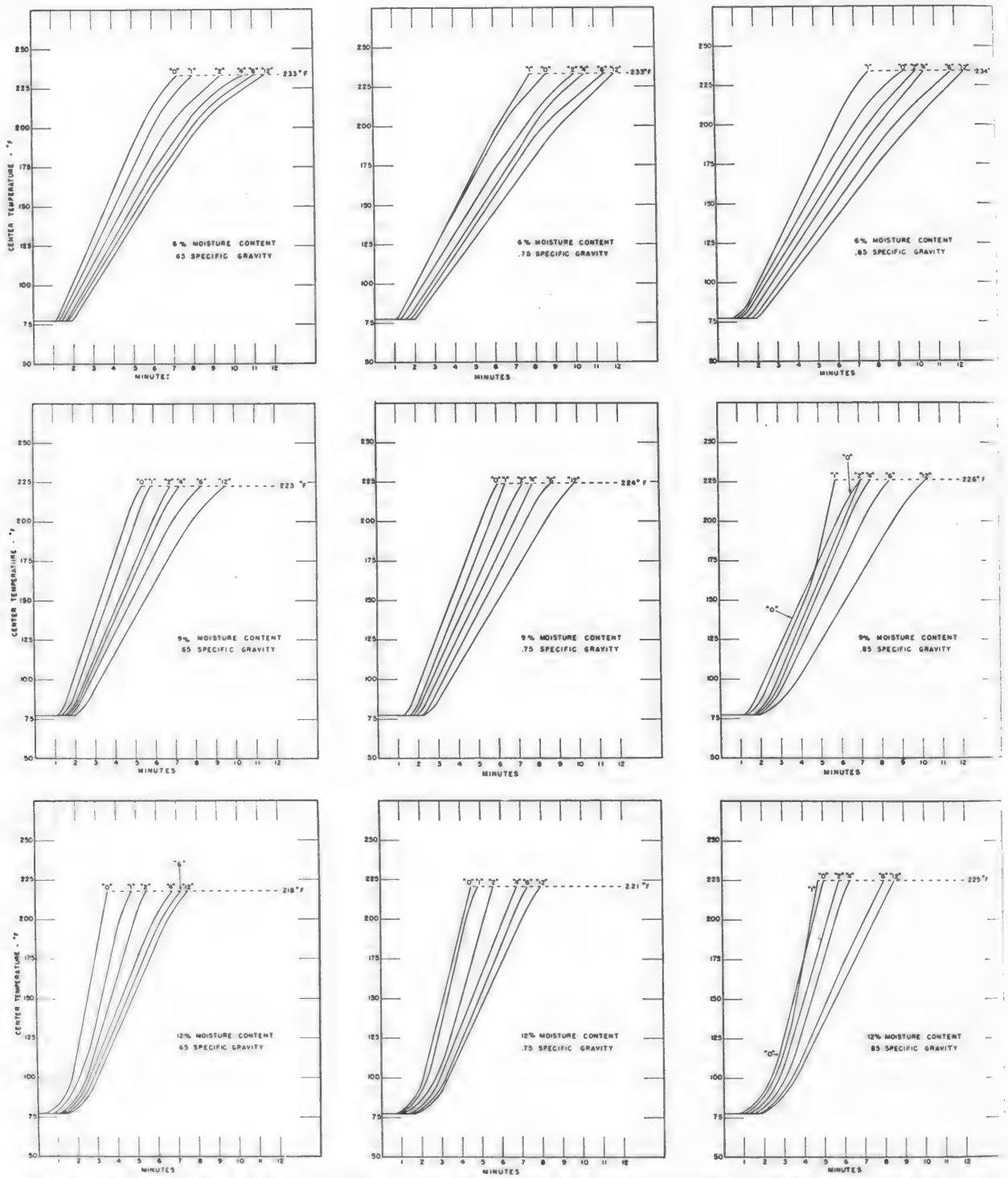
CENTER TEMPERATURE - °F
MINUTES
6% MOISTURE CONTENT .65 SPECIFIC GRAVITY
6% MOISTURE CONTENT .75 SPECIFIC GRAVITY
6% MOISTURE CONTENT .85 SPECIFIC GRAVITY
9% MOISTURE CONTENT .65 SPECIFIC GRAVITY
9% MOISTURE CONTENT .75 SPECIFIC GRAVITY
9% MOISTURE CONTENT .85 SPECIFIC GRAVITY
12% MOISTURE CONTENT .65 SPECIFIC GRAVITY
12% MOISTURE CONTENT .75 SPECIFIC GRAVITY
12% MOISTURE CONTENT .85 SPECIFIC GRAVITY

Fig. 2.—Average rate of initial temperature rise in the center of particle boards during hot-pressing for six press cycles at three moisture content levels and three density levels. Dotted lines indicate the average maximum temperatures attained during normal hot-pressing time

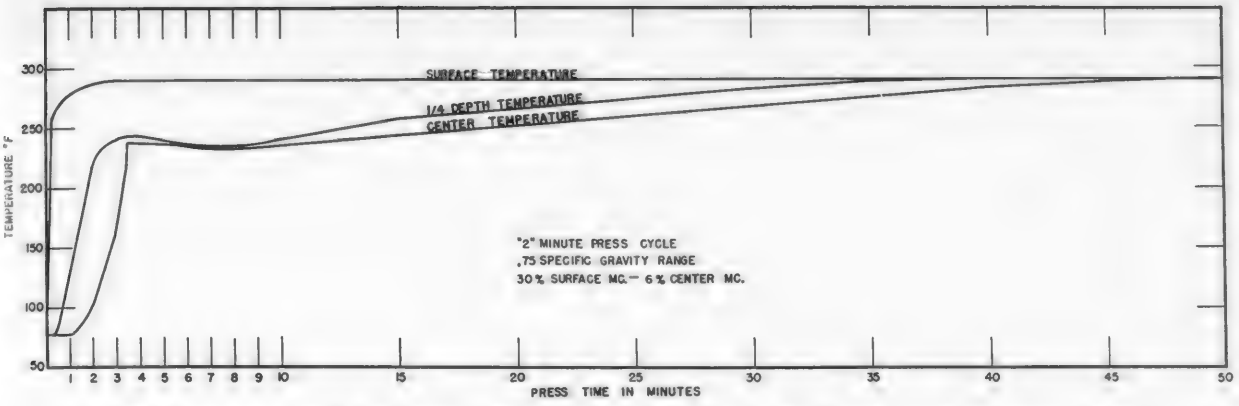

Fig. 3.—Temperature curves in the center, at ¼ depth, and on the surface of one board during the time required for the center temperature to equal the platen temperature at the board surface.

generally just twice as fast as the temperature rise in the center. Quarter-depth temperatures were not considered further in this study, therefore, since the time required to reach resin-curing temperatures in the center of boards determines over-all press cycle time in commercial applications.

Platen Pressure Effect on Heat Conduction: The rate of temperature rise in flakeboards increases perceptibly with higher initial pressure. Higher pressures give more intimate contact between flakes and between individual wood fibers within flakes, and thereby enhance heat conduction. For each family of curves in Fig. 2, note the consistent rate of temperature-rise increase between press cycles as initial pressures increase. Temperatures always rise slowest in the "12" minute (constant pressure) cycles, and the rate of temperature rise always increases consistently toward the "0" (peak) cycle and the "1" minute (at maximum pressure) cycle. Only the "0" and "1" minute cycles change relative positions, and this is seen to happen as trends toward higher density and toward lower moisture content. The reasons for these trends were not determined.

Temperature generally rose slightly faster in the low-density boards than in the higher densities. The rate of increase, however, was not proportional to the decrease in material mass between density levels. Thus it can be assumed that the effect of higher absolute pressures required to compress higher density boards was to increase the heat conduction rate. The differences in heat conduction rate between density levels were much more pronounced in the supplementary experiment concerned with moisture-content distribution treatments (see Fig. 4). These differences can only be attributed to the interaction of pressure and high surface moisture content.

Pressure also adds a small amount of heat of friction. A temperature rise of 5°F. was noted in a mat pressed to 1400 psi between cold platens.

The Effects of Moisture on Heat Penetration: The role that moisture plays in heat penetration during hot pressing is extremely complex. Exactly what happens to it and how it reacts is not completely known. The effects of moisture on heat penetration rate are clearly defined, however. Several theories on moisture reaction can, therefore, be advanced on the basis of the moisture effects.

When hot-press platens contact a particle-board mat, a decreasing temperature gradient is immediately established from the mat surface toward the center. The magnitude of the gradient will diminish as the center temperature rises. A second decreasing temperature gradient is also established from the middle area of the board to the edges along the center-line plane when heat reaches the center. Heat will flow only when a temperature gradient exists, and it flows by three means: conduction, convection, and radiation. Radiation may contribute slightly to heat flow across air voids in a particle board, but its effect can be considered to be negligible.

By nature, wood is a poor conductor. Compaction under pressure increases somewhat the conductability of wood, but convection remains the prime cause of rapid heat penetration into particle boards. The fact that moisture contributes more than pressure toward rapid heat penetration into board centers supports this thesis conclusively.

When a hot press closes on a particle board mat, the caul plates heat very rapidly. The temperature of the platen surfaces is reduced temporarily. Depending somewhat on the heat supply system of an individual press, the platens will regain the maximum temperature to which they are controlled within a minute or two. Thus, the rate of heat exchange between hot plates and wood via the caul plate comes into balance quite rapidly. Once the mat surface equals the platen temperature, the rate of heat transfer from platen to wood is governed by the temperature gradient and not by moisture content. However, the rate at which heat moves through the board from the surface is primarily a function of moisture content. Therefore, moisture content controls the rate at which the temperature gradient changes.

The moisture in the surface flakes flashes to steam within a matter of seconds after the press closes. The vapor pressure in the air voids at the surface rises accordingly. Thus a vapor pressure gradient is established from board surface to center in response to the temperature gradient. Likewise, a concurrent vapor pressure gradient is subsequently established from the middle area of the board to the edges. It is the pressure gradient that causes water vapor in the form of steam to flow toward the board center-line plane and the board edges. Heat transmission by convection is thus seen to be an effect of temperature gradient through the medium of the corresponding vapor pressure gradient.

As the surface layers dry, the vapor pressure is reduced in those layers while moisture accumulates in the center layers and the vapor pressure correspondingly increases. Therefore, the vapor pressure gradient established from surface to center at the start of the press cycle must tend to reverse itself. If the pressure gradient did actually reverse itself, however, moisture would *not* then flow back toward the surface, because the temperature gradient would repel such a tendency. Water vapor must then follow the line of least resistance and, consequently, flow along the vapor pressure gradient toward the board edges.

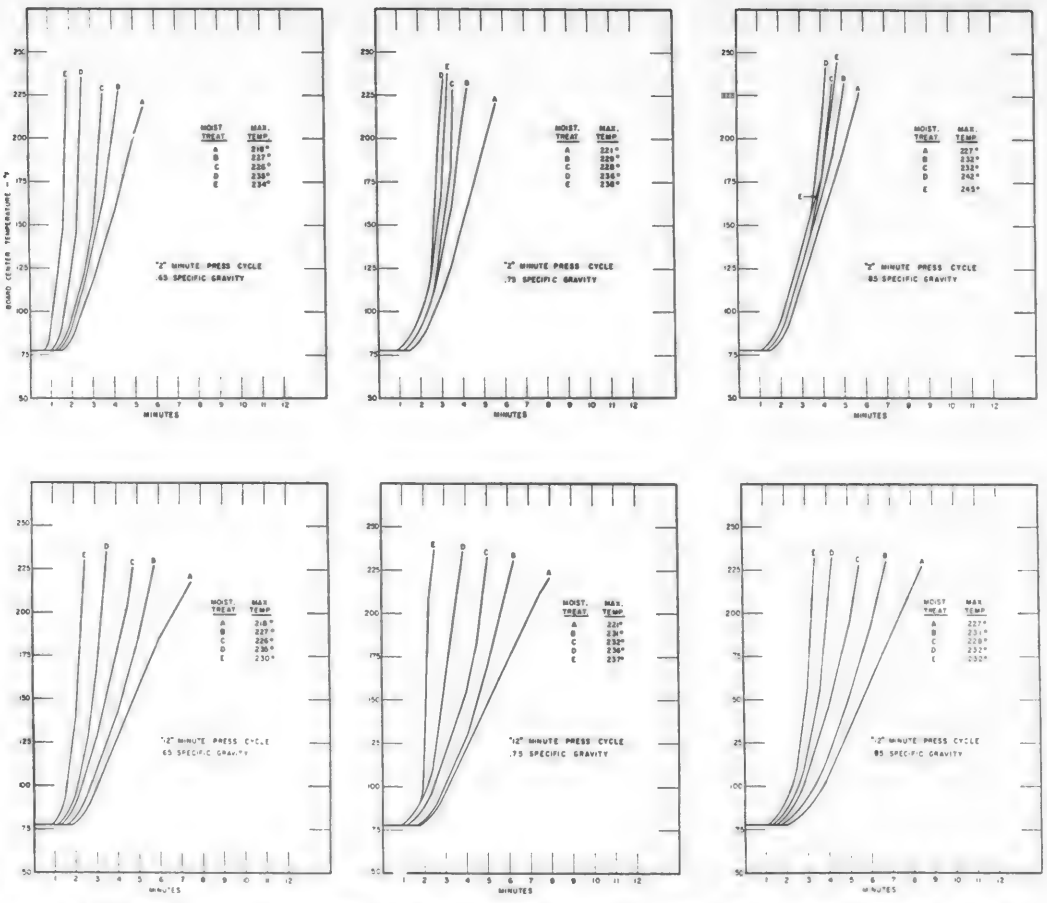

Fig. 4.—Rate of initial temperature rise in the center of particle boards during hot pressing for five moisture content treatments, two press cycles, and three density levels. The included tables indicate the initial-rise maximum temperature attained with each treatment. Moisture treatments included are as follows:

A—12% moisture content throughout
B—15% surface m.c.—9% center m.c.
C—18% surface m.c.—9% center m.c.
D—24% surface m.c.—6% center m.c.
E—30% surface m.c.—6% center m.c.

It has been shown that increases of moisture content cause faster rates of heat penetration to board centers. Fig. 4 also shows that high *surface* moisture contents additionally increase the rate of heat penetration to board centers. Note that the latter portions of the temperature curves incline more rapidly with increases of surface moisture until the temperature "skyrockets" in the more extreme cases. Only live steam penetrating to the board centers could cause such rapid temperature rises. It seems very unlikely that much, if any, moisture flows in the liquid state unless the fiber saturation point of the wood is exceeded.

Only a minute portion of the moisture in a particle board can exist in the form of vapor at any one time. It has been computed that, for a board of 0.75 specific gravity and 12 percent m.c., only a maximum of 0.75 percent of the moisture can be in the vapor state at any one time at a temperature of 250°F. This computation compares the volume that the 12 percent moisture content must occupy, if it were all in vapor state, with the volume of available void space in a particle board. The available void space is based on a specific gravity of 1.50 for cellulose. Therefore it is seen that a constant cycle of steam formation, steam flow to cooler areas, and subsequent condensation must occur. Condensed moisture, then, accumulates in the cooler center layers of particle boards until moisture loss to the edges exceeds moisture migration from the surface layers to the center layers.

The process of condensed moisture accumulation in areas of lower temperature is accentuated by the fact that, immediately after hot pressing, the edge areas of particle boards have higher moisture contents than the middle areas. A board's edge during hot pressing is naturally cooler than the middle, since heat is permitted to escape only from the edges. The lower temperature in the edge areas permits greater concentration of condensed moisture than in the middle areas.

It also would seem likely that the accumulation of moisture of condensation would be greater in low-density areas throughout a board, although there are no data to support this theory.

Particle boards rupture or "blow" when the vapor pressure in the boards exceeds the strength of the resin bonds as the platen pressure is released, and resin bonds are considerably weakened when boards are hot. It is therefore necessary for the internal vapor pressure to be low enough to preclude "blowing" at the end of the press cycle. The natural laws of steam pressure do not apply directly to particle boards because the moisture in the board is not in the free state unless the moisture content exceeds the fiber saturation point. If the moisture content does exceed fiber saturation, the vapor pressure is the same as that of free water at a given temperature.

Free water will evaporate at ... times at temperatures above freezi... and at relative humidities less tha... 100 per cent, but water in wood ... less than fiber saturation is adsorb... (held to the molecular structure ... the wood by hydrogen bonds). As t... moisture content of wood decreas... the attraction between the wood a... the adsorbed moisture increases. Ther... fore the adsorbed moisture content ... the wood establishes the amount ...

vapor pressure at a given temperature. Thus it is seen that the vapor pressure within wood at less than fiber saturation is the vapor pressure of free water minus the attraction of wood for water at any given temperature and moisture content. The attractive force between wood and water prevents most of the water from contributing to the internal vapor pressure. This explains why particle boards often do not "blow" even though they contain more than enough moisture to do so at the time the platen pressure is released.

The total resistive force of the particle board mat against the pressure of the platens is a combination of the mechanical resistance of the wood plus the summation of forces due to vapor pressure within the board.

For any given set of conditions, moisture content controls the center temperature after the initial temperature rise. The maximum temperature achieved by the initial temperature rise increases as the over-all moisture content decreases, as shown in Fig. 2. The higher moisture contents presumably cause higher vapor pressures, which force moisture to flow to the edges and escape more rapidly. Thus water is "boiled off" faster from the center and depresses the temperature more when moisture contents are higher. Coupled with the fact that the lower moisture content boards did not compress as readily and therefore contained better avenues of moisture escape, the theory of m.c. controlling center temperature gains more stature.

Fig. 4 carries accompanying tables of maximum center temperatures attained by boards of various surface moisture contents. These tables clearly indicate that boards of high surface moisture content and low center moisture content reached appreciably higher center temperatures. This infers that the accumulated center moisture content was considerably lower in boards of high initial surface moisture content during the elapsed time of the press cycle. Lower center densities (Fig. 6) also support this theory.

The complete temperature curves of Fig. 3 show that the temperature at the board center rose quite rapidly to a point of temporary equilibrium (the top of the temperature curve after the initial temperature rise). The temperature held constant for a short time, then slowly dropped a few degrees, and finally began a slow climb to equal the platen temperature. The temperature dip, which was quite pronounced throughout the study, can logically be explained as follows: the maximum temperature in the center of the board was attained by the initial temperature rise before the highest moisture content accumulation was reached. As the moisture content in the center increased, it would seem that the liberated heat of condensation should have raised the temperature rather than allow a drop. Vapor pressure increased also, however, and accelerated the rate of moisture movement to the board edges. Concurrently, the surface layers lost moisture to the center, and the heat conduction rate through the surface layers declined. The heat loss to the atmosphere then exceeded the rate of heat conduction from the platens to the center and the center temperature dipped.

Finally, moisture loss to the atmosphere reduced the moisture content at the board center; internal vapor pressure and rate of moisture loss dropped; the rate of heat conduction again exceeded the rate of heat loss; and the center temperature gradually climbed and eventually equalled the platen temperature.

The m.c. of the board at the end of the 50-minute cycle as shown in Fig. 3 (when center temperature equalled platen temperature) was approximately 1 percent. The moisture content of boards with an initial moisture content of 12 percent was about 8 percent at the end of the 12-minute press cycle.

A second theory of the temperature dip is that exothermic heat of polymerization is added to the platen heat at the time of the initial temperature-rise maximum. Then, as resin polymerization approaches completion, the added exothermic heat diminishes and the temperature dips. This theory, as being the entire cause of the temperature dip, was exploded since the temperature dip persisted when a mat was hot pressed without resin. Actually it seems most likely that the moisture effect and the exothermic heat effect combine to cause the temperature dip.

Layer Density: Strength properties of particle boards are directly related to many factors. Species of wood, the original species density, density of the boards, type of resin adhesive, resin quantity and distribution, wax content, if used, size, character, and orientation of particles, and moisture content at the time of board testing all affect the physical properties of particle boards. Board density, however, is the one factor most frequently and directly related to strength and is the control factor used to correct and correlate the effects and results of other variables in virtually all particle board testing and research.

Press cycles, moisture content, and moisture distribution in the mat combine to determine how density is distributed in layers throughout the thickness of particle boards. In turn, layer density affects strength properties such as bending strength, internal bond strength, and lateral screw-holding ability. Consequently, it is necessary to control closely the factors that affect density stratification if boards with uniform strength properties are to be produced for a specified ultimate use.

The layer density results of four press cycles, three density levels, and three moisture content levels are shown in Fig. 5. The layer density curves of two press cycles were omitted as being unnecessary. The omitted curve for the "1" minute press cycle always falls between the "0" and "2" minute cycles in each family of curves, and the "4" minute cycle curve always falls between the "2" and "6" minute curves. It should also be pointed out that the curve points indicate only the *average* density for a given layer, and the perspective of density distribution is somewhat distorted in the case of "U" type and "S" type curves.

The effect of platen pressure can readily be discerned in each family of curves. High initial pressure results in high surface density and correspondingly low center density. For many purposes a high surface density is desirable, such as where bending strength is important, where the surface will be subject to abrasion, and where the surface will be finished or will receive a thin decorative overlay. On the other hand, where particle boards will be subjected to shear stresses or where lateral screw-holding ability is necessary, the center density should be relatively high.

The effect of moisture content on layer density can best be studied by observing the constant-pressure ("12" minute) cycle curves. One would naturally assume that density throughout the thickness of a particle board would be constant if platen pressure did not change. This is not the case, however. Note that in each instance the surface density is low, that density rises abruptly to maximum in the intermediate layers between surface and center, and that the center density drops to something between the surface density and the intermediate density.

The only plausible explanation for this phenomenon is that of moisture migration and condensed moisture accumulation as discussed previously in the heat-transmission study. Moisture moves very quickly from the surface to the intermediate layers, and the moisture content in those layers rises considerably. Moisture continues to move into the center layer, but at a more leisurely rate in response to temperatures lower than at the surface.

Thus the density of any layer throughout the thickness of a particle board depends primarily upon the pressure and the moisture content of

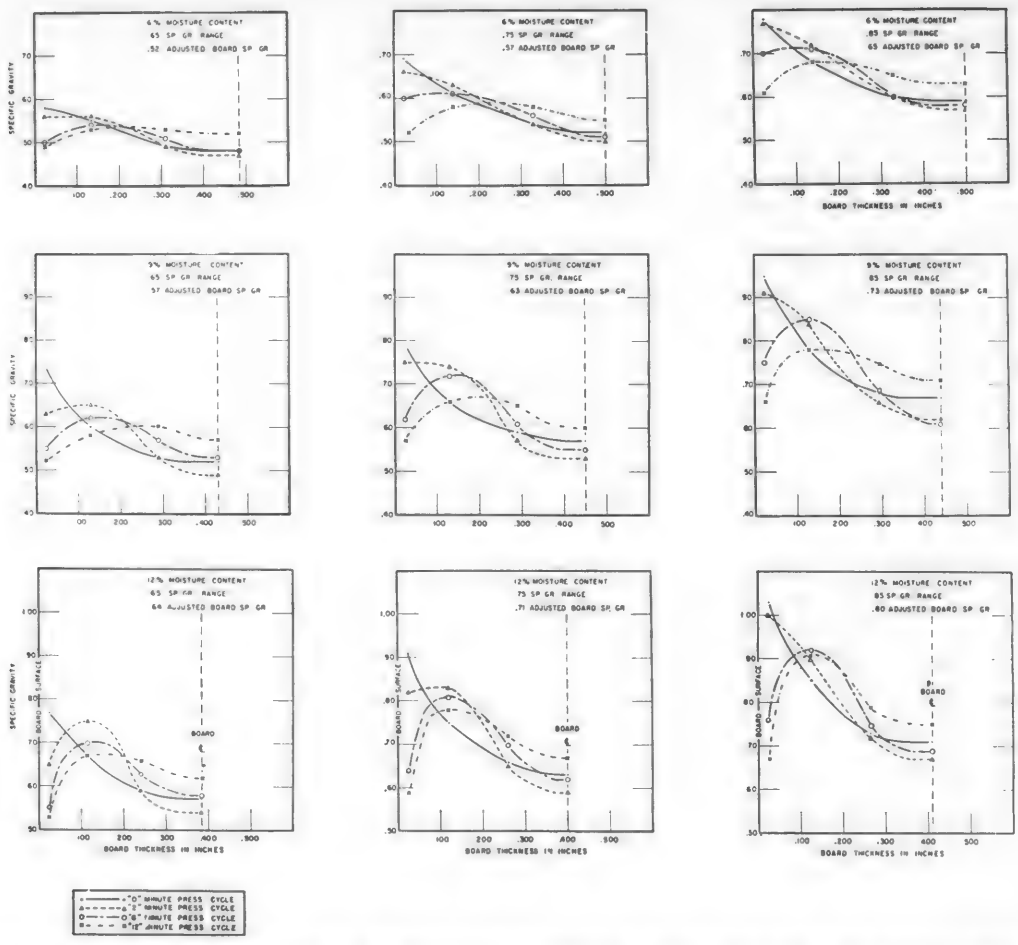

Fig. 5.—Adjusted layer density curves from board surface to center line for four press cycles, three moisture content levels, and three density levels. Curve points indicate only the average density for each layer.

that layer at the time sufficient heat reaches the layer to polymerize the resin and bond the particles together. Moisture plasticizes wood and makes it more compressible. Thus the relatively higher moisture content of the intermediate layers at the time the resin sets results in high relative density in those layers. The "4" and "6" minute (at maximum pressure) cycles reveal the same trend, while the "2" minute cycle shows the same tendency in the low density range. The high initial pressures of the "0" and "1" minute cycles completely mask the effect of moisture migration as revealed in density stratification. However, moisture migration must markedly affect layer density variations within particle boards even if its effects are masked by high initial pressure.

Moisture moves more readily in particle boards as moisture content increases, which causes greater moisture content ranges throughout high moisture content boards during pressing. Consequently, greater layer density variation throughout particle boards results from higher moisture contents.

Layer density ranges within boards also vary considerably between over-all density levels. The higher pressures required to manufacture higher over-all density boards cause more rapid movement of moisture through particle boards during pressing. The result is greater density variation within boards of the high over-all density level. This effect is magnified in view of the fact that higher density boards contain a greater mass of material that moisture must pass through and greater actual amounts of water.

The effect of high surface and low center moisture content on layer density was to increase the density of the surface and the intermediate layers directly beneath the surface and to decrease the density of center layers (see Fig. 6). Thus density variations between layers are magnified by the various moisture distribution treatments.

Modulus of Rupture: Average modulus of rupture values between the various press cycles were significant at the 1 percent confidence level by analysis of covariance. Since MOR is theoretically a test of the extreme fiber strength at the surface, it was expected that the MOR values would correlate with surface layer density values; that is, high surface density would give correspondingly high MOR strength. However, the "expected" correlation did not completely materialize. Table 1 gives the mean MOR results after adjustment by multiple regression analysis to the grand specific gravity, and Fig. 7 shows the MOR results adjusted graphically within each specific gravity range.

The average press cycle values of Table 1 were analyzed by "Multiple Range and Multiple F Test" (1). At the 5 percent level of significance, the "2" minute press cycle was significantly better than any other press cycle; the "1" and "4" minute cycles were not significantly different from each other, but they were significantly better than either the "0" or "6 minute cycles; the "0" and "6" minute cycles were not significantly different from each other; and the "12" minute cycle was significantly poorer than any other cycle. The only difference at the 1 percent level of significance from the

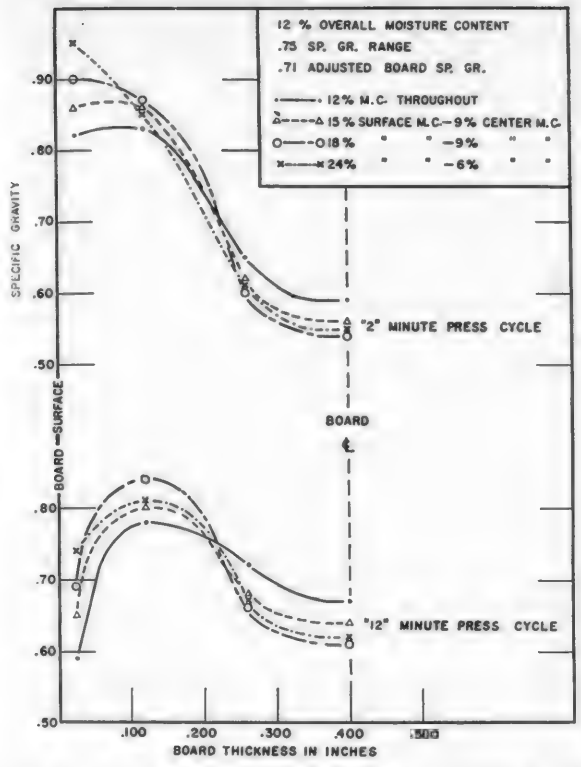

Fig. 6.—Adjusted layer density curves from board surface to center line for four moisture content treatments, two press cycles, and one specific gravity level.

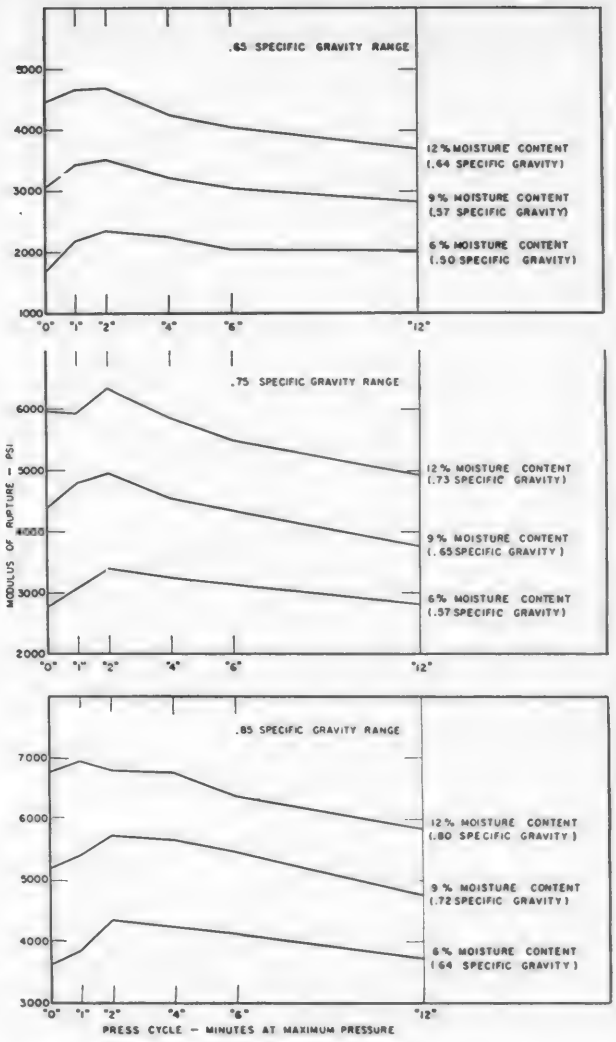
.65 SPECIFIC GRAVITY RANGE
12% MOISTURE CONTENT (.64 SPECIFIC GRAVITY)
9% MOISTURE CONTENT (.57 SPECIFIC GRAVITY)
6% MOISTURE CONTENT (.50 SPECIFIC GRAVITY)
.75 SPECIFIC GRAVITY RANGE
12% MOISTURE CONTENT (.73 SPECIFIC GRAVITY)
9% MOISTURE CONTENT (.65 SPECIFIC GRAVITY)
6% MOISTURE CONTENT (.57 SPECIFIC GRAVITY)
MODULUS OF RUPTURE - PSI
.85 SPECIFIC GRAVITY RANGE
12% MOISTURE CONTENT (.80 SPECIFIC GRAVITY)
9% MOISTURE CONTENT (.72 SPECIFIC GRAVITY)
6% MOISTURE CONTENT (.64 SPECIFIC GRAVITY)
PRESS CYCLE — MINUTES AT MAXIMUM PRESSURE

Fig. 7.—Modulus of rupture for six press cycles, three specific gravity levels, and three moisture content levels. MOR values were adjusted graphically to the average specific gravity (indicated in parenthesis) of each moisture content level.

percent analysis was that the "2" and "1" minute cycles were not significantly different.

In all cases, as shown in Fig. 7, compared to Fig. 5, MOR strength declined in direct response to surface density from the "2" through the "12" minute cycle. However, the exact opposite generally occurred from the "0" to "2" minute cycles. A logical explanation for the inverse relationship between surface density and MOR strength in the "0" to "2" minute cycles is the effect of relaxing maximum pressure quickly after it is attained. Relaxation of high initial pressures before the resin polymerizes allows considerable spring-back in the press. If the spring-back occurs before the surface resin sets, the result is poor bonding of surface flakes despite the fact that comparatively high surface density remains.

Although MOR values do not correlate with surface density in the "0" to "2" minute cycles, there is a very close correlation between MOR strength and the density of the first intermediate layer directly beneath the surface (at a depth of about 0.1 inch from the surface). This may be coincidence, but it appears that particle board MOR strength is affected considerably by density beneath the surface, and is not merely the strength of the extreme surface fiber. The formula for the derivation of MOR assumes that the material being tested is homogeneous. That particle boards are not homogeneous is clearly proven by the layer density curves of Fig. 5. This indicates that the MOR test is not entirely suited to particle board.

By analysis of covariance, the interaction between moisture content and press cycles was also significant at the 1 percent confidence level. There was a definite trend toward less difference in MOR strength between the "0" and "2" minute cycles as moisture content increased. Diametrically opposed to this trend was greater difference in surface density as moisture content increased. There was also a definite trend toward greater difference in MOR strength between the "1" and "2" minute cycles as m.c. increased. It seems likely that steam formation caused the interactions between moisture content levels within the "0" and "2" minute press cycles, but the exact cause was not determined. Fahrni (2) claims that steam formation in particle boards aids resin to flow uniformly and spread over chip surfaces before setting, and that it is desirable for steam to form at the board surface before maximum pressure is reached.

In the average moisture-content analysis (Table 1), 9 percent m.c. was significantly better than 6 percent or 12 percent, while the 6 percent–12 percent comparison was not significant. Only resin bonding can explain the difference between 6 percent and 9 percent, but surface layer density can explain, or partially explain, the difference between 9 percent and 12 percent m.c. On the adjusted basis of the analysis, the surface density of the 12 percent boards was lower than the surface density of the 9 percent boards, since increased m.c. caused greater variation in layer density throughout the particle boards.

Moisture Content Distribution Variations: In the average covariance analysis with moisture distribution as a variable, a significant difference in MOR at the 1 percent confidence level was found between press cycles and between moisture content treatments and also the interaction of press cycles and moisture treatments. The adjusted MOR values are presented in Table 2 together with symbols denoting significance. Increasing surface moisture content, beyond certain limits, had an adverse effect on MOR strength. These limits depended upon the press cycle. With the "2" minute cycle, 15 percent surface moisture content gave maximum MOR strength before the adverse effect of high surface moisture content began. With the "12" minute cycle, 18 percent moisture content was significantly better than any other treatment. At 21 percent surface m.c. however, the "2" minute press cycle was superior in MOR strength to the best obtainable with the "12" minute press cycle, despite the adverse effect of higher surface m.c. Also in the "12" minute press cycle, 24 percent surface moisture content gave MOR equal to 12 percent m.c. throughout.

Beyond 21 percent surface moisture content, the decline in MOR strength accelerated especially with the "2" minute press cycle. In fact, at 24 percent surface m.c., the "12" minute cycle was significantly better than the "2" minute cycle. The decline in MOR strength and particularly the accelerated decline beyond 21 percent surface m.c. was caused by the rate at which moisture was driven from the board surface in the early stages of the press cycle. The high pressure of the "2" minute cycle along with high temperature and excessive surface m.c. caused relatively large amounts of surface moisture to move very quickly to the substrata immediately beneath the surface. In the zone below the surface, condensed moisture accumulated to the point where the resin in that zone was diluted and "washed" into the body of the individual flakes. The fiber saturation point undoubtedly was exceeded.

Complete delamination of the surface "skin" occurred in static bending tests with the high-density specimens of the "2" minute cycle and 24 and 30 percent surface moisture content. Although high moisture content did not become critical until 24 percent m.c. was reached, and even then only in high-density and high-pressure treatments, the degradation effect of high surface m.c. on MOR strength was clearly established beyond 15 percent and 18 percent respectively for the "2" and "12" minute press cycles.

Table 1.—ADJUSTED[1] MEAN MODULUS OF RUPTURE VALUES FOR SIX PRESS CYCLES AND THREE MOISTURE CONTENT LEVELS

	Modulus of rupture (psi)						
	Press cycles						
Moisture content	"0"	"1"	"2"	"4"	"6"	"12"	Average
6%----------	3940	4253	4342	4327	4118	3995	4163 (B[2]
9%----------	4199	4434	4564	4415	4242	3767	4270 (A
12%----------	4268	4349	4508	4192	3974	3587	4146 (B
Average----------	4136 (c)[2]	4345 (ab)	4471 (a)	4311 (b)	4111 (c)	3783 (d)	4193

[1]Values were adjusted by multiple regression analysis to the grand mean specific gravity.
[2]Letters in parentheses denote significance at 1 percent confidence level. Any two values followed by the same letter are not significantly different from each other, such as (a) and (ab); but values followed by different letters are significantly different, such as (a) is significantly better than (b), and so on, after Duncan (1).

Table 2.—ADJUSTED[1] MEAN MODULUS OF RUPTURE VALUES FOR TWO PRESS CYCLES AND SEVEN MOISTURE CONTENT DISTRIBUTION TREATMENTS[2]

	Modulus of rupture (psi)		
	Press cycle		
Moisture content distribution treatment	"2" Minute	"12" Minute	Avera
12% m.c. throughout----------	5618 (a)[3]	4742 (f)	5180 (A
15% surface m.c.—9% center m.c.----------	5614 (a)	4883 (e)	5248 (A
18% surface m.c.—9% center m.c.----------	5312 (b)	5042 (d)	5177 (A
21% surface m.c.—9% center m.c.----------	5158 (c)	4845 (ef)	5001 (C
18% surface m.c.—6% center m.c.----------	5243 (bc)	5003 (d)	5122 (B
24% surface m.c.—6% center m.c.----------	4280 (g)	4742 (f)	4511 (D
30% surface m.c.—6% center m.c.----------	4343 (g)	4374 (g)	4359 (D
Average----------	5081 (A)[3]	4804 (B)	4943

[1]Values were adjusted by multiple regression analysis to the grand mean specific gravity.
[2]The over-all m.c. of all treatments was 12 percent.
[3]Letters in parentehses denote significance at the 1 percent confidence level.

Table 3.—ADJUSTED[1] MEAN MODULUS OF ELASTICITY VALUES FOR SIX PRESS CYCLES AND THREE MOISTURE CONTENT LEVELS

	Modulus of elasticity X 1000 (psi)						
	Press cycle						
Moisture content	"0"	"1"	"2"	"4"	"6"	"12"	Average
6%----------	445	458	437	445	429	419	439 (B)
9%----------	471	488	501	475	437	420	446 (AB)
12%----------	495	516	483	467	451	404	470 (A
Average----------	470 (a)[2]	487 (a)	474 (a)	462 (a)	439 (b)	414 (c)	458

[1]Values adjusted by multiple regression analysis to the grand specific gravity.
[2]Letters in parenthesis denote significance at the 1 percent confidence level. Any two values followed by the same letter are not significantly different from each other, such as, (a) and (ab); but values followed by different letters are significantly different, such as, (a) is significantly better than (b), and so on.
[3]Significant at the 5 percent confidence level.

Modulus of Elasticity: Analysis of covariance revealed significant differences of averages in modulus of elasticity at the 1 percent confidence level between press cycles and at the 5 percent confidence level between moisture contents. In the average press cycle analysis (See Table 3), there was no significant difference among the "0", "1", "2", or "4" minute press cycles. The "6" minute cycle was significantly poorer than the above four cycles, and the "12" minute cycle was significantly poorer than the "6" at the 1 percent confidence level.

At 12 percent moisture content and 1 percent confidence level, the "0", "1", and "2" minute cycles were not significantly different, but the "1" minute cycle was significantly better than the "4", "6", and "12" minute cycles. The "4" and "6" minute cycles were not significantly different from each other, while the "12" minute cycle was significantly poorer than any of the others.

At the 5 percent confidence level, there was no significant difference between 9 percent and 12 percent m.c., but 12 percent was significantly better than 6 percent m.c.

Moisture Content Distribution Variations: Moisture content distribution treatments and press cycles and the interaction of the two significantly affect the MOE property of particle boards. The only significant difference among moisture treatments with the "2" minute press cycle was that 18 percent and 21 percent surface m (with 9 percent center m.c.) wer significantly better in MOE than th 30 percent surface moisture conte treatment. A definite trend toward peak value at 21 percent surface m. is readily apparent, however (see T ble 4). Here again, as in MOR, t effect of excess surface moisture caus a decline in bending modulus.

MOE increased with *surface* m.c. i crease with the "12" minute cyc without a rapid decline beyond 21 pe cent surface m.c. Between 18 perce and 30 percent *surface* m.c. there w no significant difference, but 18 pe cent with 6 percent *center* m.c. was si

Table 4.—ADJUSTED[1] MEAN MODULUS OF ELASTICITY VALUES FOR TWO PRESS CYCLES AND SEVEN MOISTURE CONTENT DISTRIBUTION TREATMENTS

Moisture content distribution treatment	Modulus of elasticity X 1000 (psi)		
	Press cycle		
	"2" Minute	"12" Minute	Average
% m.c. throughout	613 (abc)[2]	510 (e)	562 (B)[2]
% surface m.c.—9% center m.c.	630 (abc)	545 (de)	587 (AB)
% surface m.c.—9% center m.c.	647 (ab)	576 (cd)	611 (A)
% surface m.c.—9% center m.c.	651 (a)	582 (bcd)	617 (A)
% surface m.c.—6% center m.c.	625 (abc)	626 (abc)	625 (A)
% surface m.c.—6% center m.c.	589 (abcd)	602 (abcd)	596 (AB)
% surface m.c.—6% center m.c.	571 (cd)	627 (abc)	599 (AB)
erage	618 (A)	581 (B)	600

[1]Values were adjusted by multiple regression analysis to the grand mean specific gravity.
[2]Letters in parentheses denote significance at the 1 percent confidence level.

Table 5.—ADJUSTED[1] MEAN TENSION PERPENDICULAR VALUES FOR SIX PRESS CYCLES AND THREE MOISTURE CONTENT LEVELS

Moisture content	Tension perpendicular (internal bond) psi						
	Press cycles						
	"0"	"1"	"2"	"4"	"6"	"12"	Average
6%	85	90	97	107	114	123	103 (AB)[2]
9%	100	100	102	107	114	127	108 (A)
12%	89	77	97	100	119	103	98 (B)
Average	91 (cd)[2]	89 (d)	99 (bc)	105 (b)	116 (a)	117 (a)	103

[1]Values were adjusted by multiple regression analysis to the grand specific gravity.
[2]Letters in parentehses denote significance at the 1 percent confidence level.

Table 6.—ADJUSTED[1] MEAN TENSION PERPENDICULAR VALUES FOR TWO PRESS CYCLES AND SEVEN MOISTURE CONTENT DISTRIBUTION TREATMENTS

Moisture content distribution treatment	Tension perpendicular (psi)		
	Press cycle		
	"2" Minute	"12" Minute	Over-all
12% m.c. throughout	132	151	142 (a)[2]
15% surface m.c.—9% center m.c.	131	134	132 (ab)
18% surface m.c.—9% center m.c.	130	124	127 (ab)
21% surface m.c.—9% center m.c.	100	130	115 bc)
18% surface m.c.—6% center m.c.	113	124	119 (b)
24% surface m.c.—6% center m.c.	69	123	96 (c)
30% surface m.c.—6% center m.c.	59	90	74 (d)
Over-all	105 (B)[2]	125 (A)	115

[1]Values were adjusted by multiple regression analysis to the grand specific gravity.
[2]Letters in parentheses denote significance at the 1 percent confidence level.

Table 7.—SURFACE MOISTURE CONTENT TREATMENTS[1] THAT CAUSED TENSION PERPENDICULAR SEPARATION NEAR THE SURFACE OF THE BOARDS BY PRESS CYCLE AND DENSITY LEVEL

Density level	Press cycle			
	"2" Minute		"12" Minute	
	Surface m.c. treatment	Internal bond (psi)	Surface m.c. treatment	Internal bond (psi)
0.65 sp. gr.	30%	105	----	---
.75 sp. gr.	24%	55	----	---
	30%	47	30%	143
.85 sp. gr.	18% (9% center m.c.)	140	----	---
	18% (6% center m.c.)	115	----	---
	21%	79	----	---
	24%	24	24%	141
	30%	10	30%	67

[1]Corresponding internal bond values indicate the degree to which surface moisture content and pressure affect bonding beneath particle-board surfaces.

nificantly better than 15 percent and 18 percent with 9 percent *center* m.c., and was significantly better than 12 percent m.c. throughout. In the average analysis, the 18 percent and 21 percent *surface* m.c. treatments were significantly better than 12 percent m.c. throughout.

Hot-pressing moist wood that is quite plastic alters the physical character of the wood itself on the board surface. It becomes harder, more brittle, and less elastic. The lignin flows and helps to cement the surface fibers to a hard, plastic-type surface. According to Kollman (4), particle board surfaces that are hot pressed with high surface moisture content acquire more dimensional stability in response to subsequent changes in moisture content. Thus, increasing the moisture content of surface particles within limits (18 to 21 percent m.c.) improves the surface character of the boards and increases bending strength properties.

Internal Bond (Tension Perpendicular Test): Internal bond strength was significant at the 1 percent confidence level for press cycles and moisture content, and at the 5 percent confidence level for the interaction of the two. The average press cycle analysis (see Table 5) revealed that the "12" and "6" minute press cycles were significantly better in internal bond than the other cycles. It also revealed that the "2" and "4" minute cycles were not significantly different; that the "2" and "0" minute cycles were not significantly different from each other, but that the "2" and "4" minute cycles were significantly better than the "1" minute cycle; and that the "4" was better than the "0" cycle. Thus, the press cycles that produced superior MOR and MOE values were inferior for producing maximum internal bond strength. In the practical density ranges, therefore, maximum MOR can only be developed at the expense of internal bond strength or vice versa.

In the average analysis between moisture content levels, the 9 percent level was significantly better than the 12 percent level. The 6–12 percent, and 6–9 percent comparisons were not significant. The apparent explanation for the significant difference between 9 percent and 12 percent m.c. lies in the interaction of two factors: One: on the adjusted basis of the analysis, the center density of 12 percent m.c. boards was lower than that of the 9 percent m.c. boards (increased m.c. caused greater layer density variation); two: optimum conditions for resin bonding seemed to be provided at 9 percent m.c. level. Poor resin bonding at the 6 percent m.c. level compensated for the differences in center density to cause a lack of significance between the 6 percent and 12 percent m.c. levels.

It was expected that internal bond strengths would closely correlate with the layer density of the boards' center lines (see Fig. 5). However, the anticipated correlation did not completely materialize. To understand the reasons for this phenomenon, it is necessary to consider the complex actions and reactions that occur when the resin is polymerized in the board center. With the "O" press cycle, the center of the board was compacted by high pressure. Then the pressure was relaxed to a relatively low "holding" pressure *before* the resin set. Relaxation of the high pressure before complete polymerization of the resin permitted considerable "spring-back" of the board while it was still in the press. Then the resin bonded the flakes that were previously compressed and subsequently allowed some degree of "springback". The steam that carried polymerizing heat to the board center raised the vapor pressure, which tended to reduce the contact pressure between

individual flakes. The result was poor internal bonding despite relatively high center density.

On the other end of the scale, the "12" minute cycle (and the "6" minute cycle with 12 percent m.c.) maintained maximum pressure until resin polymerization in the board center was complete. As far as pressure was concerned, then, the constant-pressure cycle provided optimum conditions for resin bonding in the board center.

The cycles between "0" and "12" present a pattern between the two extremes of center bonding conditions. In most of these press cycles, platen pressure was relaxed and vapor pressure increased during the time the resin was setting.

Density and internal bond strength cannot be divorced, however, because there was a definite correlation between the two at different density levels when the treatment did not change. When press cycle and moisture content treatments vary, however, internal bond strength is affected by factors other than density.

Moisture Content Distribution Variations: In the average moisture-content-treatment analysis at the 1 percent confidence level (see Table 6), the 12 percent m.c. throughout treatment was significantly better in internal bond than the 18 percent surface—6 percent center m.c. treatment and the 21, 24, and 30 percent surface m.c. treatments. The 24 percent surface m.c. treatment was significantly poorer than the treatments with a surface m.c. lower than 21 percent, and the 30 percent m.c. treatment was significantly poorer than any other treatment. With the "2" minute press cycle, the first significant difference occurred between the 18—9 percent and 18—6 percent m.c. treatments. With the "12" minute cycle, 12 percent m.c. throughout was significantly better than the 18 percent and 24 percent surface m.c. treatments, but the big drop did not occur until the 30 percent surface m.c. treatment level was reached. Here again, as in the MOR analysis, excessive moisture concentration in the substrata immediately beneath the surface caused very poor resin bonding.

It is interesting to note which treatment specimens in the tension perpendicular tests broke immediately beneath the surface instead of on the board's center line. The density level is also a factor, because the platen pressure affected the rate at which moisture was driven from the surface. Table 7 presents the treatment specimens that broke near the surface by press cycles and density level; it also includes the corresponding internal bond strength. The high density and high surface m.c. specimens had virtually no bonding at all beneath the surface. Marginal strengths above 100 psi very nearly approximated the center line internal bond strengths. Table 7 dramatically illustrates how platen pressure affected the rate at which the surface moisture migrated.

A moderately good correlation was established between center-layer density and internal bond strength for any one press cycle and density level that was unaffected by excessive surface moisture. It was not established that different center moisture treatments affected internal bonding significantly. However, decreasing center moisture content in response to increasing surface moisture content caused decreases in center-layer density.

The test results of this research indicate that moisture content between 9 percent throughout and surface m.c. treatment that approached fiber saturation at some point in the board during the pressing operation had little effect on adhesive bonding action. There are no data to substantiate this belief, since it is virtually impossible to differentiate between the effect of moisture on resin bonding and the effect of moisture on the compressibility of wood.

2- and 24-Hour Water Absorption: Analysis of covariance in the main experiment revealed that press cycles and moisture content did not significantly affect the rate of water absorption during the 2-hour soak test. Press cycles were also not significant during the 24-hour soak test, but the 6 percent moisture content level was significantly poorer than the 9 percent or 12 percent m.c. level at the 5 percent confidence level. There was no difference betwen 9 percent and 12 percent m.c.

Press cycles and moisture distribution treatments in the supplementary experiment showed significant differences at the 5 percent confidence level in the 2-hour water absorption test. In the 24-hour water absorption test, all significant differences disappeared. The "2" minute press cycle was significantly better than the "12" minute cycle in the 2-hour water absorption test. Apparently the harder surfaces of the "2" minute cycle boards inhibited water absorption during the short soak time. The difference disappeared during the longer, 24-hour soak period, however.

In the 2-hour soak test, the 12 percent m.c. throughout treatment was significantly better at the 5 percent confidence level than the 21, 24, and 30 percent surface m.c. treatments. The areas of poor bonding beneath the surfaces of the high surface m.c. boards permitted faster water absorption in the short soak period. Again, all significant differences disappeared in the 24-hour soak test.

2- and 24-Hour Thickness Swell: In the 2-hour thickness swell test, the average press cycle and moisture content analyses were not significant, but the interaction of the two variables was significant at the 1 percent confidence level. At 6 percent m.c. the "0" and "1" minute cycles were significantly poorer in 2-hour thickness swell than the other cycles. At 9 percent m.c. the "0" cycle was significantly poorer than the "2", "6", and "12" minute cycles. At 12 percent m.c. there was no significant difference between any of the press cycles.

In the 24-hour average thickness swell test, the "0" and "1" minute press cycles were significantly poorer than the other cycles at the 5 per cent confidence level. The interaction of press cycles and moisture content was signficant at the 1 percent confidence level. At the 6 percent level the "0" cycle was significantly poorer than the "2" minute cycle, and "0" and "1" minute cycles were significantly poorer than "4", "6", and "12" minute cycles. At 9 percent m.c., the "6" and "12" minute cycles were significantly better than the "0" cycle, and at 12 percent m.c. the "12" minute cycle was significantly better than the "0" and "1" minute cycles.

Here again, as in the MOR test, the "0" and "1" minute cycles were definitely inferior despite the high surface density.

In both the 2- and 24-hour thickness swell tests with high surface m.c. treatments, the "2" minute cycle was significantly better than the "12" minute cycle at the 1 percent confidence level. The significant differences between press cycles actually occurred at the 15, 18, and 21 percent surface m.c. levels. The combination of high surface moisture content (within limits) and high initial pressure, developed boards with more dimensional stability in thickness swell than did high surface moisture and low constant pressure. Again the main difference was the surface property of high density (more dimensionally stable) when the board was compressed with high surface moisture content.

With the "2" minute press cycle there was no significant difference in thickness swell between the 12, 15, 18, and 21 percent surface m.c. treatments at the 1 percent confidence level. The 24 and 30 percent surface m.c. treatments were significantly poorer, however. The difference was excessive thickness swell in the poorly bonded areas beneath the surfaces of boards with very high surface moisture content.

One important concept illustrated by these results is that wood tends to become more dimensionally stable as pressing m.c. increases. Kollman (4) found that particle board *surfaces* compressed with high surface m.c. are more dimensionally stable to subsequent moisture changes than boards pressed with relatively low surface m.c. The thickness swell results of this experiment tend to substantiate Kollman's findings.

2- and 24- Hour Linear Expansion: The average covariance analysis of linear expansion in the main experiment revealed that press cycles and moisture content were signficant at the 1 percent confidence level. The interaction, however, was not significant for either the 2- or the 24-hour test. There was no significance between 9 percent and 12 percent moisture content levels, but the 6 percent level was significantly poorer than the other two. Here again, decreased resin bonding efficiency at 6 percent m.c. is indicated.

The "0" press cycle was significantly poorer than the "1" minute cycle, and both "0" and "1" were significantly poorer than the other cycles. Although there was no significant difference between the "12", "6", "4", and "2" minute cycles, there was a constant decline in linear expansion stability in the order given.

In the linear expansion test with moisture content distribution treatments, there was no significant difference between the "2" and "12" minute press cycles, but surface moisture treatments were significant at the 1 percent confidence level. The interaction was also not significant. In both the 2- and 24-hour tests, the 12 percent m.c. throughout treatment was significantly better than the other treatments. There was no significant difference between any of the treatments with higher surface moisture contents.

Conclusions

1. During hot pressing, the rate of initial heat penetration to the center of particle boards increases: (a) as the over-all moisture content of the particle board mat increases, (b) as the surface moisture content of the particle board mat increases, and, (c) as initial platen pressure increases.

2. Moisture content controls the temperature in the center of particle boards after the initial temperature rise.

3. Press cycles, moisture content, and moisture content distribution affect the layer density throughout the thickness of particle boards.

4. Layer density influences the strength properties of particle boards.

5. The "2" minute (at maximum pressure) press cycle developed significantly superior modulus of rupture strength.

6. Within limits, high surface moisture content significantly improved modulus of rupture strength. The greatest improvement occurred with the constant-pressure cycle.

7. Excessively high surface moisture content caused poor bonding in the layers immediately beneath the board surfaces. High-pressure cycles aggravated the condition.

8. High-initial-pressure cycles and high surface moisture content (within limits) developed significantly superior modulus of elasticity.

9. Constant-pressure press cycles developed significantly superior internal bond strength compared to high-initial-pressure cycles.

10. High surface moisture content (with correspondingly low center moisture content) treatments adversely affected internal bond strength.

11. Press cycles and moisture content did not generally affect the rate of water absorption in the 2- and 24-hour soak tests.

12. High-initial-pressure press cycles (maintained less than two minutes) developed boards with significantly inferior thickness swell properties.

13. High surface moisture content (within limits) and the "2" minute at maximum pressure cycle developed boards with significantly superior thickness swell properties.

14. Linear expansion stability improved as press-cycle time at maximum pressure increased.

15. High surface moisture content treatments caused significantly poorer stability in the linear expansion tests.

Appendix

Calculation of Material Felting Weight in Particle Board Mats: The steps in the calculation of material felting weight consisted of: 1) computing the final conditioned board weight, 2) computing the final conditioned weight of the board components, and 3) computing the component weights at the time of felting. The formula for the 0:65 specific gravity and 6 percent m.c. boards is as follows: board length x width x thickness x density x conversion factor = final conditioned board weight in grams. 13″ x 13″ x 0.75″ x 0.65 sp. gr. x 16.4 cc/cu. in. = 1351 grams. The final conditioned board was composed of wood, resin, and moisture.

Then:
1.13 wood = 1351 grams
Wood (oven dry wt.) = 1195 grams
Resin solids (0.05 wood) = 60 grams
Moisture (0.08 wood) = 96 grams
Total Component Weight = 1351 grams

Finally, the felting weight was determined as the weight of components at the time of felting as follows:

Wood (oven dry weight) =	1195 grams
Resin solids (0.05 wood) =	60 grams
Moisture (0.06 wood) =	72 grams
Material felting weight =	1327 grams

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Floor Discussion

Question: What technique was used to obtain a differential moisture content in the particles?

Mr. Strickler: We would first spray the resin on the flakes, and then spray on the water.

Question: Were all flakes at the same initial moisture content?

Mr. Strickler: All with the exception of the 6 percent group. These were redried.

Question: You mentioned that some surface flakes were in the 24 to 30 percent moisture content range. Did this high surface moisture content cause any blows?

Mr. Strickler: No, during the pressing the surface moisture was driven into the interior.

Question: Were the boards pressed to stops?

Mr. Strickler: No.

Question: Were the boards sanded after pressing?

Mr. Strickler: No, however we do plan a future experiment in which we will press to stops and sand.

TREATING HARDWOOD POSTS BY THE Double-Diffusion Method[1]

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Less than 2% of the 19 million posts treated in 1956 were hardwoods. The simple equipment required for double diffusion treatments make the process a "natural" for utilizing small southern hardwoods.

Fig. 3.—Test plot at Whitehall Experimental Forest of the University of Georgia, in which posts are inspected periodically to determine their average service life.

This paper describes some exploratory experiments in the double-diffusion treatment of posts of several hardwood species native to Southeastern United States. The work was conducted as a cooperative project between the U. S. Forest Products Laboratory, the Southeastern Forest Experiment station, and the School of Forestry, University of Georgia.

From the earliest times in this country, hardwoods of varied durability have been our most extensively used material for fence posts. Today, in the Southeast, only one hardwood species, black locust, is of commercial importance. Farmers in ever-increasing numbers are using treated posts to meet their fencing needs—but they are using mostly softwoods. Of the more than 19 million posts treated commercially in 1956, moreover, southern pine accounted for 90 percent and all pines accounted for more than 98 percent of the total production. Sweetgum, the principal treated hardwood post produced, accounted for approximately 1/2 of 1 percent.

Although the Southeast, especially the Piedmont region, contains an abundance of available hardwood material, little of it is being used as treated posts. This points to a possible use for many of the less durable hardwoods that, because of lack of certain desired qualities, are of little or no value for other purposes. The development of a simple but effective means of treating hardwood posts, either commercially or on the farm, would be a step toward better utilization of low-value hardwoods.

Simple Preservative Application

The double-diffusion process is one of the newer nonpressure methods for treating wood by means of relatively simple equipment. It consists of soaking green wood first in one chemical solution and then in a second chemical solution. The two chemicals diffuse into the wood and then react with each other to form a compound that is toxic to termites and wood-destroying fungi. Since the compound that is formed in the wood is practically insoluble, it shows little tendency to leach from wood exposed to wet conditions. The method appears especially promising for the treatment of round wood products such as fence posts.

There are several methods for applying the treatment. For example, posts may be treated by being completely immersed in the solutions contained in tanks, or they may be stood upright in barrels. The choice between these methods depends largely upon the number of posts to be treated and the equipment available.

The barrel method offers the advantage of low investment in equipment and appears to be practical for treating a limited number of posts on a farm. The tank method, whereby the posts are completely immersed in the solutions, appears more practical than the barrel method for treating a considerable number of posts, as would be done in commercial operations.

Previous to the present investigation, experiments on double-diffusion method had been confined chiefly to the treatment of pine fence posts either by the tank or barrel method.[3] [4] There had been a few treatments of hardwood posts made by the barrel method but none by the tank method. For a number of reasons that need not be enumerated here, it was believed that commercial treatments rather than on-the-farm treatments offered greater promise for the utiliz-

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[1] A contributed paper, submitted Sept. 10, 1958.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[3] Baechler, R. H. 1953. Effect of treat variables on absorption and distribution chemicals in pine posts treated by double diffusion. Jour. FPRS, V. 3, No. 5, p. 170.

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Fig. 1.—Chemicals and water are mixed in a tank by means of compressed air to obtain a homogeneous solution.

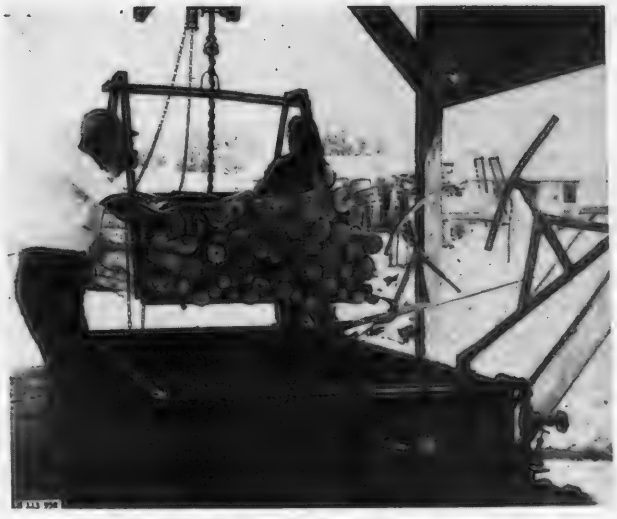

Fig. 2.—Operators position a charge of 60 posts before lowering it into the treating tank.

tion of hardwoods. It was therefore decided to use the tank procedure in exploring the applicability of double diffusion to the treatment of several southern hardwood species.

In addition to the variations in procedure in double-diffusion treatments, there are also variations in the chemicals that may be used. A number of different combinations of chemicals are suitable and are giving encouraging results in field tests designed to determine their relative effectiveness. Several of these chemical combinations involve copper sulfate, which is corrosive to steel. While the precipitate formed in the wood is noncorrosive, such treatment requires that one container be made of a material other than steel. Since both of the tanks available at the testing site—the University of Georgia Forestry School—were of steel, it was necessary to choose a combination of chemicals that could be held in steel tanks. The chemicals selected were zinc sulfate mixed with arsenic acid in a proportion of approximately 6:1 in the first bath, and only sodium chromate in the second bath. The precipitate, formed when the three chemicals combine in the wood, consists of a mixture of zinc arsenate and zinc chromate, with the latter predominating. Pine posts treated with these chemicals by the standing-in-barrel method are performing well in tests started in 1951.

Since the comparative treatability of the different hardwoods was the major point of interest, it was decided to keep to a minimum the variations in other factors. The work plan that was prepared called for the treatment of round fence posts of approximately the same average size and degree of greenness. The treatments were to be made by complete immersion in unheated solutions of the same chemicals at approximately the same concentrations. Three time schedules were adopted for treating, namely 1 day, 2 days, and 3 days in each solution.

The hardwood species selected for investigation were red oak, white oak, sweetgum, hickory, and yellow-poplar. Loblolly pine was added for comparison. A few cypress posts were also included.

A few exceptions to the foregoing plan should be noted. To obtain some data on the feasibility of reducing time and improving penetration by heating the first solution, some additional posts were treated by one time schedule of one-half day in each solution with the first solution being heated to approximately 200° F. and the second remaining unheated. Also, 6 green sweetgum crossties and a small amount of green 1-inch sweetgum lumber were treated according to one time schedule and with unheated solutions.

Experimental Procedure

Material Treated: Except for the cypress, the posts were cut on the property of the University of Georgia. They were 7 feet long, and varied in mid-diameter from approximately 2½ to 5 inches. A small percentage fell outside this range. The sweetgum, yellow-poplar, and loblolly pine posts were largely sapwood. The white oak had sapwood bands of ½ to 1 inch; the red oak had somewhat less sapwood. It was difficult to determine the thickness of the sapwood band on the hickory posts, which varied from ½ inch to more than 1 inch.

The cutting of the posts was arranged so that treatment nearly always started within a day or two after they were cut; in most cases, treatment started on the same day that the posts were cut. With one exception, peeling was withheld until the day of treatment.

Preparation of Solutions: All chemicals used were of the cheapest grade, namely the technical grade. The first solution was made by adding to the first tank the calculated amounts of water, zinc sulfate crystals, and arsenic acid in the form of 75 percent solution. A stream of compressed air was used to help dissolve the chemicals and obtain a homogeneous solution (Fig. 1). A little insoluble matter—probably a mixture of zinc, magnesium, calcium, phosphates and arsenates—remained suspended in the solution. The second solution was prepared by adding the calculated amounts of water and anhydrous sodium chromate to the second tank and mixing them by means of a stream of air.

After treated posts were removed from the solutions, additional amounts of chemicals were added to replace the chemicals absorbed by the posts. Some water also was added to replace that lost by evaporation. The amounts of chemicals to be added were usually estimated from readings of specific gravity made with a hydrometer. Tables are available that give the concentration corresponding to the specific gravities of various solutions. This method is sufficiently accurate for practical purposes. At the start of each treatment, however, samples were taken and subsequently analyzed to obtain the data on concentrations given in the following tables.

Treatments: Each charge consisted of 30 posts of each of two species, or a total of 60 posts. The posts were labeled with copper numbering tags before being lowered into the first tank and weighted down with pieces of iron. After the required time in the

first solution—either ½, 1, 2, or 3 days, depending upon the scehdule for the group—the posts were raised from the solution. They were rinsed with a slow stream of water until most of the solution was removed from the surfaces. After a short period of draining, the posts were transferred to the second solution and again weighted down. After the required time in the second tank, they were removed and rinsed. They were then piled and covered with a plastic sheet or tar paper to retard drying and permit further inward diffusion of the chemicals. After being covered for 3 weeks, the posts were open piled for seasoning. Fig. 2 shows the equipment used in the treatments.

One large post, one small post, and three additional posts, selected at random from each group, were sent to the Forest Products Laboratory for chemical analysis. The remaining 25 posts of each group were installed in a test plot on the Whitehall Experimental Forest of the University of Georgia (Fig. 3). These posts are being inspected annually to determine the average service life for each group.

Cypress posts constituted an exception to the foregoing. Since they were not readily available at the time of treatment, only five were treated according to each schedule. None was placed in field test, since all posts were cut up for chemical analysis.

Three sweetgum boards and three sweetgum crossties that were treated as exploratory experiments (Fig. 4) were also analyzed.

Sampling of Material for Analysis

To obtain data for the average absorption of chemical by posts in a group, the five sample posts were first ripped down the middle. A 1-inch disk was then cut from the middle of each foot of half post. These disks were ground together to form a composite sample for the post. Equal portions of ground wood were mixed together to form a sample for the group. The analysis of this sample gave the same value, within experimental error, as would have been obtained by analyzing separately the samples for individual posts and determining the arithmetic mean of the values obtained.

To obtain some data on distribution, some supplementary analyses were made on the outer ¾ inch and the inner core of disks cut from the groundline area of a number of posts. The posts selected were 3½ to 4 inches in diameter, which is somewhat larger than the average. Visual observations indicated that fair to good penetration had been obtained in the loblolly pine, yellow-poplar, sweetgum, and cypress

Fig. 4.—Treatment of sweetgum crosstie and lumber.

posts that had been soaked for 1 day in each solution. Disks were therefore cut from such posts rather than from posts treated by use of longer schedules. In the case of hickory and the oaks, disks were cut from posts given a 3-day treatment in each solution. An additional hickory and one red oak post were sectioned from the treatment in which the first solution was heated. Disks from the oak posts were divided into sapwood and heartwood portions; only the heartwood was analyzed.

The sweetgum boards were first cut into quarter sections. To reduce the amount of wood to be ground, opposite quarter sections were discarded. The two remaining quarter sections were marked into 8-inch lengths, and a 1-inch cross section was cut from the center of each 8-inch segment. The 1-inch cross sections were then ground together to form a sample for the board. A composite sample for the three boards was then made.

A similar procedure was used to form a composite sample for the three ties.

Chemical Analyses: The samples were first digested by the method described by Baechler and Servais.[5] The amount of zinc was determined by the AWPA method for zinc[6] in Boliden salts. Arsenic was distilled off as the trichloride and titrated with standard iodine. Chromium was also determined iodometrically.

The analyses yielded results on the basis of percent by weight. These figures were converted to pounds per cubic foot of wood by multiplying them by the following factors: Yellow-poplar, 28; loblolly pine, 35; cypress, 32; sweetgum, 34; red oak, 44; white oak, 48; and hickory, 51. These factors were derived from the specific gravities of air-dried sections taken from typical posts of each species.

[5] R. H. Baechler and Philip Servais. The Determination of Nickel and Copper Chromates and Nickel, Copper, and Magnesium Arsenates in Treated Wood. AWPA Proceedings 38: pp. 19–23 (1942).

[6] AWPA Standard A2–58, Standard Method for Analysis of Water-Borne Preservatives.

Results and Conclusions

The absorption of chemicals by the posts, lumber, and crossties is shown in Table 1. The table reveals several cases where the data for a given species do not fall into a regular order. In such cases the results of chemical analyses were confirmed. It appears probable that the experimental error may be due to the inclusion of one or more abnormal posts in the five sample posts of a group.

If attention be directed to the total absorption (Table 1, last col.) obtained by treating posts with cold solutions, it will be seen that the species fall into the following order: Yellow-poplar, sweetgum, cypress, white oak, red oak, loblolly pine, and hickory. The higher absorption in four of the hardwoods as compared with loblolly pine is an exception to the results generally obtained by nonpressure treatments.

The absorption of chromate by the loblolly pine posts was very low, which more or less accounts for the fact that pine definitely absorbed less total chemical than did yellow-poplar and sweetgum. Sodium chromate reacts with certain extractives in pine, and this retards the diffusion of the chemical. In previous treatments by the barrel method, it had been found that sodium chromate diffused inward and moved longitudinally more readily in some hardwoods than in pine.

The total absorption obtained with cold solutions was in some cases higher than would be desirable from the standpoint of cost. Retention as high as 1.5 pounds has been used in commercial pressure treatments with standard waterborne preservatives. It is felt that, in double-diffusion treatments, conditions should be controlled so as to keep total absorption below 2.0 pounds per cubic foot. In line with this premise, it follows that the yellow-poplar and sweetgum posts were overtreated when immersed for longer than 1 day in each solution. Even with a 1-day schedule, somewhat weaker solutions are probably desirable. This also is true for the treatment of 1-inch sweetgum lumber. The total absorption, as shown by white oak, red oak, loblolly pine, and hickory posts, as well as by the sweetgum crossties, fell within a practical range.

Heating the first solution greatly accelerated the uptake of chemicals. Except in the case of the oaks and hickory, absorption was higher than would be desired in practice. Shorter immersion periods or weaker solutions

han were used in these experiments ppear to be advisable for yellow-oplar, sweetgum, and loblolly pine. The ratio of the chemicals absorbed use of cold solutions was fairly tisfactory except in the case of lob-lly pine, which absorbed too little romate in proportion to zinc ab-rbed. The difference was much greater than had been found in treatments made by the barrel method. For treating pine by the tank method, the chromate solution probably should be several times as strong as the zinc solution, or else the soaking time in the chromate should be longer.

The data also indicate that, when the first solution is heated and a balanced time schedule is used, the first solution should be considerably stronger than the second. Another means of achieving better balance in the amounts of the chemicals absorbed would be to increase the ratio of time in the first bath to time in the second bath.

The results of chemical analyses to

ble 1.—RETENTION OF CHEMICALS IN POSTS, LUMBER, AND CROSSTIES TREATED BY DOUBLE DIFFUSION AT ATHENS, GA., JUNE 1955

No.	Species	Time in each solution[1] Days	Concentrations of solutions			Absorption of chemicals			
			$ZnSO_4$ Percent	H_3AsO_4 Percent	Na_2CrO_4 Percent	$ZnSO_4$ Lb. per cu. ft.	H_3AsO_4 Lb. per cu. ft.	Na_2CrO_4 Lb. per cu. ft.	Total Lb. per cu. ft.
30	White oak	1 + 1	15.44	2.86	21.67	0.56	0.14	0.57	1.27
1[illegible]-210	White oak	2 + 2	16.38	2.91	19.43	.63	.19	.69	1.50
[illegible]390	White oak	3 + 3	17.48	2.97	20.76	1.01	.23	1.02	2.26
[illegible]60	Yellow-poplar	1 + 1	15.44	2.86	21.67	1.01	.21	.77	1.99
2[illegible]-240	Yellow-poplar	2 + 2	16.38	2.91	19.43	1.62	.33	1.02	2.97
3[illegible]-420	Yellow-poplar	3 + 3	17.48	2.97	20.76	1.48	.32	1.35	3.15
[illegible]90	Loblolly pine	1 + 1	16.12	2.78	21.28	.85	.20	.12	1.17
2[illegible]-270	Loblolly pine	2 + 2	16.01	2.98	20.97	.82	.20	.18	1.20
4[illegible]-450	Loblolly pine	3 + 3	17.34	2.96	20.79	1.46	.31	.49	2.26
91-120	Sweetgum	1 + 1	16.12	2.78	21.28	.98	.23	.72	1.93
271-300	Sweetgum	2 + 2	16.01	2.98	20.97	1.11	.26	1.04	2.41
451-480	Sweetgum	3 + 3	17.34	2.96	20.79	1.31	.30	1.27	2.88
121-150	Red oak	1 + 1	16.24	2.81	21.54	.34	.12	.58	1.04
301-330	Red oak	2 + 2	16.94	3.10	21.00	.71	.17	.69	1.57
481-510	Red oak	3 + 3	17.45	2.93	20.92	.76	.18	1.13	2.07
151-180	Hickory	1 + 1	16.24	2.81	21.54	.18	.06	.15	.39
331-360	Hickory	2 + 2	16.94	3.10	21.00	.33	.10	.27	.70
511-540	Hickory	3 + 3	17.45	2.93	20.92	.44	.13	.46	1.03
Cy1–Cy5	Cypress	1 + 1	17.45	2.93	20.60	.76	.15	.53	1.44
Cy6–Cy10	Cypress	2 + 2	17.45	2.93	20.42	.90	.19	.99	2.11
Cy11–Cy15	Cypress	3 + 3	17.45	2.93	20.42	1.57	.31	1.09	2.97
541-570	White oak	½ + ½[2]	19.73	3.12	21.20	.47	.13	1.09	1.69
571-600	Yellow-poplar	½ + ½[2]	19.73	3.12	21.20	.88	.18	2.60	3.59
601-630	Loblolly pine	½ + ½[2]	19.14	3.12	20.90	.80	.14	1.17	2.11
631-660	Sweetgum	½ + ½[2]	19.14	3.12	20.90	.90	.18	2.05	3.13
661-690	Red oak	½ + ½[2]	20.56	3.22	20.95	.64	.14	.82	1.60
691-720	Hickory	½ + ½[2]	20.56	3.22	20.95	.29	.08	.41	.78
1" lumber	Sweetgum	3 + 3	19.92	3.07	20.76	3.01	.53	1.67	5.21
Crossties	Sweetgum	3 + 3	19.92	3.07	20.76	.70	.13	.49	1.32

[1]Cold solutions unless otherwise indicated.
[2]Solution held at approximately 200° F.

Table 2.—DISTRIBUTION OF CHEMICALS IN SAMPLE POSTS

Species	Time in each solution[1] Days	Absorption of chemicals								
		Outer ¾ inch			Inner core			Heartwood		
		$ZnSO_4$ Lb. per cu. ft.	H_3AsO_4 Lb. per cu. ft.	Na_2CrO_4 Lb. per cu. ft.	$ZnSO_4$ Lb. per cu. ft.	H_3AsO_4 Lb. per cu. ft.	Na_2CrO_4 Lb. per cu. ft.	$ZnSO_4$ Lb. per cu. ft.	H_3AsO_4 Lb. per cu. ft.	Na_2CrO_4 Lb. per cu. ft.
Sweetgum	1	0.58	0.12	0.30	0.034	0.014	0.47	-----	-----	-----
Yellow-poplar	1	.31	.067	.47	.048	.011	.009	-----	-----	-----
Loblolly pine	1	.88	.24	.17	.021	.010	.002	-----	-----	-----
Cypress	1	.36	.11	.41	.000	.006	.016	-----	-----	-----
Red oak	3	-----	-----	-----	-----	-----	-----	0.004	0.008	0.002
Red oak	½[2]	-----	-----	-----	-----	-----	-----	.026	.017	.022
White oak	3	-----	-----	-----	-----	-----	-----	.005	.010	.000
Hickory	3	.46	.12	.30	.000	.010	.004	-----	-----	-----
Hickory	½[2]	.25	.075	.32	.000	.015	.000	-----	-----	-----

[1]Cold solutions unless otherwise indicated.
[2]First solution heated.

Table 3.—VISUAL OBSERVATION OF PENETRATION IN POSTS

Time in each solution Days	Depth of penetration in posts of various species						
	Yellow-poplar (largely sapwood) Inches	Loblolly pine (largely sapwood) Inches	Sweetgum (largely sapwood) Inches	Cypress Inches	Red oak (Sapwood dpeth ⅛ to 1 inch)	White oak (Sapwood depth ½ to 1 inch) Inches	Hickory (Sapwood depth ½ 1 inch) Inches
1[1]	1½	scant ¾	½	⅜	Complete sapwood penetration, no heartwood penetration.	⅛–¼	1/16
2[1]	Nearly complete	¾	½–⅝	⅝–¾	Complete sapwood penetration, no heartwood penetration.	¼–½	[illegible]
3[1]	Complete	⅞ of solid penetration, streaks inside.	1¾	1[illegible]⅝	Complete sapwood penetration, no heartwood penetration.	Complete sapwood penetration—⅝ inch, no heartwood penetration.	3/16
[illegible]	Complete	Complete	Complete		Complete sapwood penetration, a little heartwood penetration.	Complete sapwood penetration, no heartwood penetration.	At least ¼ (irregular)

[1]Both solutions cold.
[2]First solution heated.

show distribution are given in Table 2. Penetration as shown by analyses was in some cases deeper than had been observed visually.

Table 2 shows that a penetration of somewhat greater than ¾ inch was obtained when a 1-day schedule was used in the treatments of yellow-poplar, sweetgum, loblolly pine, and perhaps cypress. Practically no penetration into the heartwood of oak was obtained when cold solutions were used with a 3-day schedule. When the first solution was heated, a slight penetration into the heartwood of red oak occurred. The poor penetration observed visually in hickory was confirmed by chemical analysis. Heating the first solution definitely improved penetration according to visual observation, but failed to produce satisfactory penetration according to chemical analysis.

The inner core of the groundline section of the sweetgum post analyzed for distribution was found to contain a higher concentration of chromate than did the outer ¾ inch. In investigations of diffusion at the Forest Products Laboratory, this was the first exception encountered to the rule that concentrations of chemicals decrease with distance from the periphery. It was first thought that an error had been made in the analysis. A second disk was therefore sectioned and analyzed with practically the same results being obtained. This surprising finding will be checked in future treatments. There was no apparent difference in rate of growth to explain the result. Moisture determinations were not made; as a rule, the heartwood of sweetgum contains less moisture than the sapwood. A possible explanation may lie in the reducing action of extractives that are found in greatest amounts in the heartwood. Such extractives enter into complex reactions with chromates whereby insoluble compounds containing chormium in tricalent form are produced. This would set up a steep concentration gradient that would accelerate the inward diffusion of sodium chromate. In the chemical analysis, total chromium is determined and is calculated as sodium chromate.

During the sectioning of the material for analysis, selected sections were sprayed with a reagent to show the presence of zinc. The visual observations of depth of penetration of zinc in posts are given in Table 3. It may be added here that the 1-inch sweetgum lumber had been almost completely penetrated, as was the sapwood of the sweetgum crossties. The heartwood of the crossties, however, had not been penetrated.

In summation, double diffusion appears to offer considerable promise as a means of treating some hardwoods, and merits further investigation.

Douglas-Fir Plywood:

ITS TREATED AND NATURAL RESISTANCE TO TERMITES[1]

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Laboratory tests showed that untreated Douglas-fir plywood is not resistant to eastern subterranean termites. Wood volume loss was used to differentiate between treated and untreated specimens after 25 days.

Fig. 1.—Typical condition of Douglas-fir plywood test sections after exposure to subterranean termites. Untreated sections (left to right): C6, C2, C9 (side views).

LABORATORY METHODS TO SCREEN native woods for subterranean termite resistance and investigate wood preservative-termite relationships have not been satisfactorily developed in this country. There are a number of reasons for this, but probably the biggest deterrent has been the supposed difficulty in the laboratory handling of subterranean termites coupled with the lack of knowledge as to the extent of their damage, although in recent years an estimated annual loss of $150 to $200 million has been attributed to termites and other wood-destroying insects.[2]

While investigators in the United States have been neglecting this field, other countries (Australia, Germany, and the Union of South Africa) have been seriously and aggressively examining termites and their relationships to treated wood.

The test method reported in this paper has been used previously to determine the threshold retentions of certain eastern subterranean termites for some water-borne preservatives.[3]

Accelerated laboratory tests, when properly handled and their limitations realized, can eliminate unnecessary

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[1] A contributed paper, received July, 1958. The plywood data in this paper were obtained in a study by the author for the U. S. Plywood Corp. in cooperation with the School of Forestry, Duke Univ.

[2] Reported by the U. S. Forest Products Laboratory, Madison, Wis.

[3] Lund, A. E. 1958. The relationship of subterranean termite attack to varying retentions of water-borne preservatives. Presented before the 54th Annual Meeting, American Wood-Preservers' Assoc.

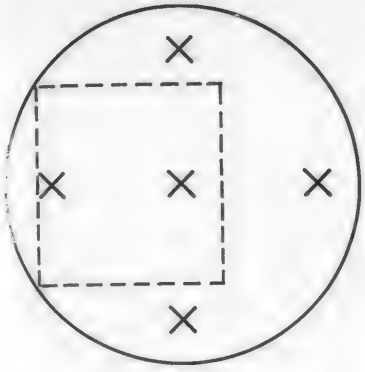

Fig. 2.—Top-view diagram of test container showing plywood block position and termite descent openings.

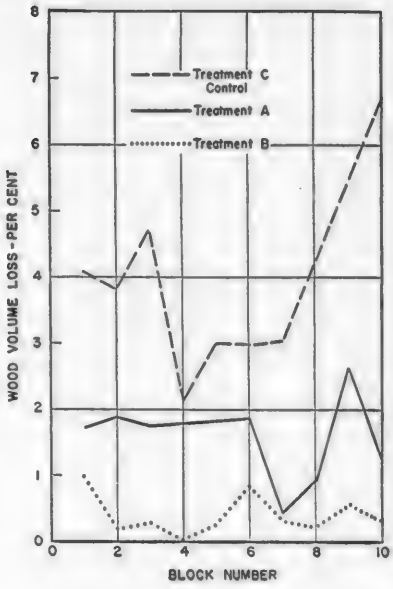

Fig. 3.—Volume loss comparisons between treated and untreated plywood test block sections.

and expensive initial field-test screening, which often takes extended periods and yields inconclusive data because of variable environmental factors, insect distribution, and population levels. After laboratory tests, field or service testing should be scheduled for those compounds that show enough promise to warrant the expense and time involved. The present study differentiates between the natural resistance and two experimental treatments of Douglas-fir plywood when exposed to subterranean termite attack.

Experimental Procedure

The 30 test blocks used in this project were made from Douglas-fir plywood of 5-ply construction. The wood averaged between 16 and 37 rings per inch. Block dimensions 5/8 by 2 by 2 inches. Three series used were:

A—10 specimens treated with a wood preservative.

B—10 specimens with a different preservative treatment.

C—10 untreated specimens for "natural resistance" determination.

The blocks were lightly sanded before they were tested to remove any loose splinters and to facilitate subsequent surface inspections for termite activity. After the blocks were sanded, they were conditioned at 80° F. and 90 percent relative humidity for 12 days to insure volatilization of the preservative carrier (determined by absence of odor) and to increase their moisture content and thus lessen the deletion of the container-sand moisture.

Subterranean termites (*Reticulitermes virginicus* (Banks))[4] were removed from a fallen decayed tree and allowed to remain for approximately 16 hours between moistened paper toweling and filter paper before inclusion in the test chambers. This method facilitated the separation of weak and dead individuals from the more healthy specimens. Termite mortality was reduced by handling only the paper that the termites were clinging to rather than the insects themselves. Termite test containers consisted of standard 1 pint widemouth canning jars with a 3/8 inch hole drilled in the approximate center of the metal top to allow for aeration. A piece of 40 mesh phosphor-bronze screen (similar to gasolene strainer screen) was soldered over the opening to prevent egress of the termites.

Light brown sand, free of organic matter, was used in the test jars. Certain physical properties of this medium were determined by standard test methods and are summarized below.[5]

Particle size	Percent	Moisture equivalent, Percent
1.0 -2.0 mm	11	1.31
.50-1.0	56	----
.25- .50	17	----
.10- .25	15	pH
.05- .10	1	5.0
- .05	neg.	

The sand was oven-dried and sterilized at 300° F. for 24 hours before being used.

Test containers for the plywood sections were made up using 410 grams of the oven-dry sand and 82 grams of distilled water. About 1/2 of the sand was placed in the container. The plywood test block was inserted in a horizontal position with one edge adjacent to a glass side to allow visual checks on termite activity within the container without disturbing the contents. Containers were given identifying numbers, and then the remaining portion of the sand was added and leveled. The jars were filled to about 2/3 of their capacity. The specified amount of distilled water was added, and the jars were capped and then allowed to remain for about 12 to 14 hours to permit uniform wetting of the medium.

Each jar then was uncapped and 5 holes were made in the sand, as indicated in Fig. 1, with a metal dissecting needle. Three of these were punched to the bottom; the remaining 2 intercepted the plywood test block. A paper funnel was inserted into the jar opening and individual filter papers to which termites were clinging were gently agitated to transfer the insects to the jar. Visual estimates of the number of termites on each paper were made, while actual counts were made at intervals to check these estimates. Termites were added until an estimated 150 (with less than 10 percent of the non-wood-destroying soldier forms) were included in each container. Caps were replaced and the test jars were placed in a constant temperature and humidity chamber at 80° F. and 90 percent relative humidity for 25 days.

After one day, a number of the jars were examined for termite activity and to determine if a majority of the termites had descended beneath, or remained on, the surface of the sand. On the second day, all containers were examined for termite movement and position, mortality, and tunnel consrtuction. The second complete inspection was made after seven days. A third examination was made after 13 days, which was followed by a fourth inspection after 18 days. After 25 days, the test blocks were removed and inspected. This consisted of recording termite activity, position, and mortality. Upon removal, the plywood test blocks were brushed to remove sand particles, rinsed in water, and examined for visible termite damage. Void areas were measured to the closest 0.5 mm by means of metal probes, a binocular microscope, and a flexible mm scale. The number of faces of each test sample that showed evidence of termite activity was recorded. Plywood test sections were photographed to show the damage (Fig. 3) with the side pictured selected to show the heaviest attack.

Visual comparisons based on one side, as pictured, may not present an

[4] Collected through the cooperation of Prof. J. B. Huffman of the University of Florida and identified by Dr. Thomas E. Snyder, Washington, D.C.

[5] Laboratory tests conducted by H. C. Row, Duke University.

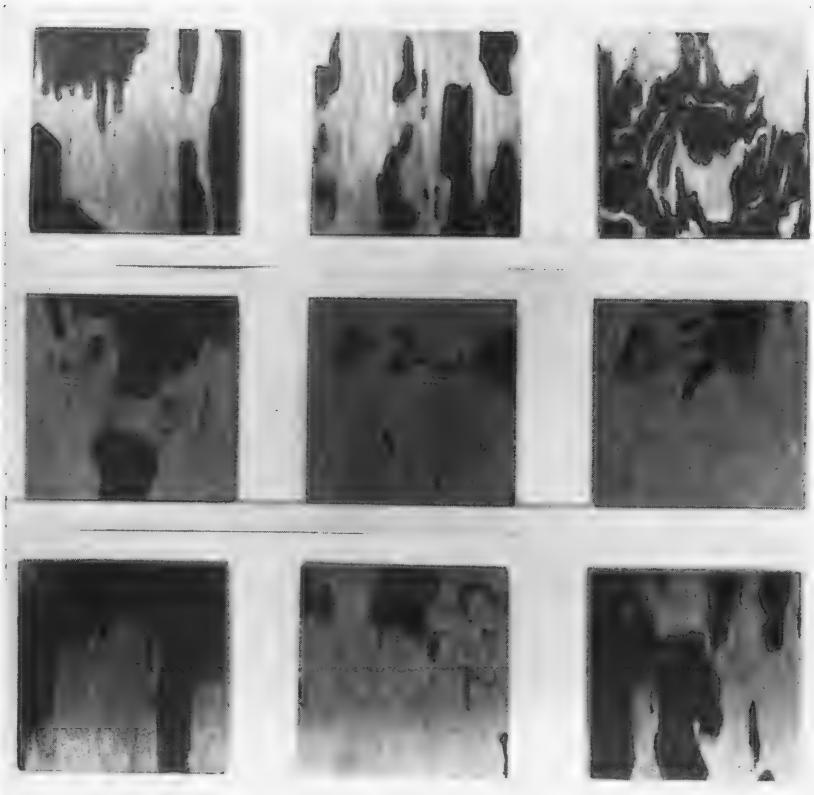

Fig. 4.—Typical condition of Douglas-fir plywood test sections after exposure to subterranean termites. Darker portions, stained with India ink, are termite attack areas. Left to right, top to bottom: Treatment A1, A2, A3; B1, B2, B3; C1, C2, C3.

accurate estimate of the damage to a particular series of specimens. Fig. 4, for example, shows the termite attack on a second face of control samples.

Results

Inspections: At a preliminary inspection of a number of the containers after one day of testing, termite movement was vigorous as evidenced by extensive tunnel systems beneath the sand surface. The bottom of a test container with typical tunnel construction is shown in Fig. 5.

After two days: The first complete examination of all containers after two days revealed that the termites had consrtucted numerous tunnels throughout each test jar, and that a majority of the insects in all containers in Series A were beneath the surface of the medium. In Series C there were no termites visible on the medium surface. In Series B, however, the majority of the termites in 7 of the 10 test chambers had reappeared on the surface of the sand.

Mortality, indicated by dead insects on the sand surface, had taken place in Series A and Series B containers. In most cases the death rate was very low, averaging about 0.67 percent. Two dead insects per chamber were noted in four of the control series containers. Nevertheless, vigorous activity was observed in all 30 test jars at this examination.

After seven days: Further mortality was noted in Series A and Series B. Vigorous activity beneath the sand surface, with no added mortality, was exhibited in all Series C test jars, while there was no visible termite movement in two chambers of Series B and one of Series A.

After 13 days: The third examination was completed with additional termite mortality exhibited in Series A and Series B. There was no evidence of added mortality in Series C jars where vigorous activity was observed. In the one jar holding live termites of Series B and also in one of two containers holding live termites in Series A, the insects were on the surface. All termites were beneath the medium surface in all chambers of Series C.

After 18 days: Vigorous activity was maintained in Series C jars with no observed mortality. Termites were under the sand surface. No visible movement was noted in any of the containers of Series B, while one chamber in Series A exhibited insect activity.

After 25 days: At the last inspection, there was no termite movement noted in any of the jars of Series A and B, while vigorous activity was observed beneath the medium surface in the containers of Series C. When the test chambers were emptied, no live insects were found in the jars of Series A or B. Tables 1 and 2 summarize the results obtained from the five inspections.

General: All 30 of the test specimens showed evidence of termite attack, with the different series showing variation in the amount of wood consumed by the insects (Fig. 2). Volume loss averaged 4.0 percent for the control series (C) and substantially less for Series A and B. The number of faces attacked per plywood section also varied between series. Attacked faces averaged 5.9 for Series C.

Because activity was noted in all containers of the control series at the termination of this study (25 days) a figure of 25+ was assigned to Series C.

The data for volume loss and the number of faces attacked for each individual test section are presented Table 1.

None of the blocks examined at the conclusion of the test exhibited obvious visible decay as determined by wood color and hardness. Microscopic examinations to uncover fungal infection have not been completed on these test blocks.

Discussion

Previous experimentation has shown that the approximate average for "normal" mortality due to starvation and handling procedures was between 12 and 16 days for the species of termites used under the conditions encountered in these studies. The death rate followed a sigmoid curve pattern, with the few weak individuals dying first followed by a large majority of the normal healthy insects. The few very hardy termites expired last.

Experimental work completed previous to this study made it possible to rate water-borne preservatives by using criteria of weight loss, volume loss, termite mortality, number of specimen faces attacked, and estimated killing time. The one criterion judged to be most reliable (and also more

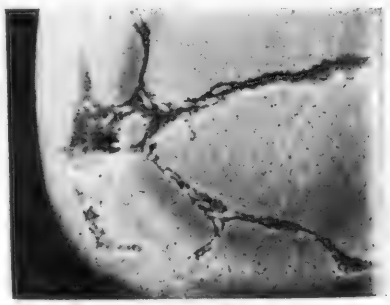

Fig. 5.—Bottom view of test container, showing typical tunnel construction.

laborious) was volume loss measurement. Most of the other determinants were confounded by masking influences that destroyed their accuracy. The number of test-specimen faces that exhibited termite attack were again recorded in this study with the hope that it would prove a fast and reliable method of evaluation, but more experimentation appears necessary before its validity as a measure of attack can be determined. Volume loss measurement seems to present the most accurate picture of termite attack.

A question that arises is: is Douglas-fir resistant or non-resistant to subterranean termite attack? Laboratory data, which shows that untreated Douglas-fir plywood suffered an average 4 percent volume loss over 10 samples in 25 days, would indicate that it is not resistant. Results from an earlier study, previously referred to, indicated that solid southern yellow pine blocks lost 6 percent in volume after 25 days of termite exposure. In comparing these two figures, influencing factors must be scrutinized. This study was originated two months later than the southern yellow pine research, and this time interval may have influenced the composition of the insect group used within each container so that their feeding rates were affected. Further study may show that the discrepancy is of the magnitude that may be charged to a laboratory test of this nature, or may show that different loss rates are to be expected when comparing plywood specimens to lumber specimens.

It is important in laboratory tests that all the specimens (excluding those treated with true repellants) show evidence of termite attack, although for very toxic materials or high preservative retentions it may be necessary to examine the specimens under a microscope to detect the damage. Evidence of attack indicates vigor of the insect group.

Discretion must be used in labeling a particular species of wood as resistant to termite attack, for it may be "resistant" only through insect selectivity based on the woods palatability. Thus if two woods are present, with one being more palatable than the other, the less palatable wood may not suffer extensive damage. If the wood that had "resistance through insect selectivity" is the only food source available, however, then it will lose immunity to serious termite attack. A second point in labeling a wood termite-resistant is that it very easily makes it "termite-proof" to the general public.

Summary and Conclusions

Douglas-fir plywood test sections that included three treatments (two with preservatives, one control) were tested for resistance to subterranean termite attack by a laboratory method. This test differentiated between the three treatments by means of test criteria of wood volume losses and the number of test-section faces attacked.

Untreated Douglas-fir, (Treatment C) was seriously attacked by subterranean termites—thus failing to prove that Douglas-fir has termite resistance, although it may be less palatable to termites than other woods.

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Table 1.—ESTIMATED KILLING TIME[1], VOLUME LOSS MEASUREMENTS, AND NUMBER OF BLOCK FACES ATTACKED FOR 30 PLYWOOD TEST BLOCKS AFTER A 25-DAY EXPOSURE TO SUBTERRANEAN TERMITES

Block No.	Number of faces attacked[2]	Volume loss, mm³	Volume loss, percent,	Estimated killing time, days
A 1	6	665.50	1.71	13
2	5	725.50	1.86	13
3	6	682.88	1.75	13
4	4	688.25	1.76	13
5	6	714.61	1.83	13
6	5	725.00	1.86	25
7	5	170.00	0.44	18
8	5	357.25	0.92	13
9	3	1,018.50	2.61	13
10	4	470.51	1.21	7
Average	4.9	621.80	1.60	14.1
B 1	5	388.38	0.99	18
2	3	69.25	0.18	13
3	3	114.75	0.29	13
4	3	13.25	0.03	7
5	3	103.88	0.27	13
6	3	338.75	0.87	13
7	3	124.51	0.32	13
8	3	90.25	0.23	7
9	3	222.87	0.57	13
10	3	124.63	0.32	13
Average	3.2	159.05	0.41	12.3
C 1	6	1,589.61	4.07	25+
2	6	1,493.75	3.83	25+
3	6	1,841.13	4.72	25+
4	6	832.12	2.13	25+
5	6	1,169.24	3.00	25+
6	5	1,162.76	2.98	25+
7	6	1,179.75	3.02	25+
8	6	1,654.75	4.24	25+
9	6	2,098.24	5.38	25+
10	6	2,594.50	6.65	25+
Average	5.9	1,561.58	4.00	25+

[1] Observations made after 2, 7, 13, 18 and 25 days of testing.
[2] Maximum = 6.

Table 2.—TERMITE BURROW CONSTRUCTION[1] AND TERMITE POSITION AT OBSERVATION CHECKS

Block No.	Position of termite majority[2] after: 2 days	7 days	13 days	18 days	25 days
A 1	Down	Down	0	0	0
2	Down	Down	0	0	0
3	Down	Down	0	0	0
4	Down	Down	0	0	0
5	Down	Down	0	0	0
6	Down	Down	Down	Up	0
7	Down	Down	Up	0	0
8	Down	Down	0	0	0
9	Down	Down	0	0	0
10	Down	0[3]	0	0	0
B 1	Down	Down	Up	0	0
2	Up	Up	0	0	0
3	Up	Down	0	0	0
4	Up	0	0	0	0
5	Up	Up	0	0	0
6	Down	Down	0	0	0
7	Up	Up	0	0	0
8	Up	0	0	0	0
9	Up	Up	0	0	0
10	Down	Up	0	0	0
C 1	Down	Down	Down	Down	Down
2	Down	Down	Down	Down	Down
3	Down	Down	Down	Down	Down
4	Down	Down	Down	Down	Down
5	Down	Down	Down	Down	Down
6	Down	Down	Down	Down	Down
7	Down	Down	Down	Down	Down
8	Down	Down	Down	Down	Down
9	Down	Down	Down	Down	Down
10	Down	Down	Down	Down	Down

[1] Checked after two days of testing at which time extensive tunneling noted in all 30 containers.
[2] "Down" indicates that the majority of remaining live visible termites were beneath the surface of the sand; "Up" means on the surface.
[3] "0" Designates no visible termite activity observed at check period.

THE CHEMICAL NATURE AND IMPORTANCE OF

Extraneous Components of Wood[1]

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The extraneous components often lend individuality to specific woods, whose odor, decay resistance, etc., must be ascribed to such components rather than to usual cell-wall constituents. Our native hardwoods warrant the bulk of immediate future research in this field.

AT THE OUTSET, it might be well to define what is meant by "extraneous components" because the term is certainly not self-explanatory. In such a definition, a distinction is made between the cell-wall components and those which are not a part of the cell wall.

The cell walls of all mature woods contain largely cellulose, together with lignin and the hemicelluloses, substances that form interpenetrating systems and that, in place, are insoluble in *cold* water and in *neutral* organic solvents. Besides these three major components, the cell wall may hold others in very small amounts, for example, certain kinds of mineral matter.

Extractives

All woods also contain certain amounts of a wide variety of organic (and some inorganic) substances that can be extracted with cold water and that are soluble in such neutral organic solvents as ether, chloroform, the alcohols, benzene, ligroine, and methylene chloride. Often mixtures of solvents (such as 50 per cent ethanol or ethanol-benzene) are used. These soluble substances are usually termed the extractives. It should be noted that *cold* water (20° C.) was stressed as a neutral solvent. Hot water, especially over an extended extraction period, has a hydrolytic effect on certain of the cell-wall components of the wood, and gradually splits off acyl groups and thus furnishes a degradative acid medium.

So, although the literature is replete with data on hot-water extractives, these may be contaminated with secondary products formed during the treatment. As an example, a jack pine sawdust studied by Green and Leaf (1)[2] when extracted 25 hours with *cold* water lost about 1 per cent. After another 75 hours this loss was little changed. This same sawdust when extracted 100 hours with *boiling* water lost 18 per cent of its weight.

Neutral organic solvents are required in a wood extraction. An alkaline solvent, like ethanolamine, may well remove extractives, but it is also quite effective as a delignifying agent.

Nonextractable Extraneous Components

Besides the extractives, there are substances in many woods that remain insoluble under the conditions mentioned, but that are quite distinct from the cell wall itself. To give a few examples, there are the starch grains in certain hardwoods, which are insoluble in cold water and in neutral organic solvents, and which show up when stained with iodine. By careful manipulation, these can be separated mechanically from the xylem and their shapes can be explored microscopically. Various woods also contain crystals c calcium oxalate, which are visible ur der the microscope, and which, a though imbedded, cannot be consi ered cell-wall components. These, to are highly insoluble.

Certain tropical woods have heav inclusions of silica that are discrete an extraparietal. Often these siliceous d posits, if present in relatively larg amounts, will render a timber highl resistant to marine borers. Accordin to a favored definition, the extraneou materials include *both* the extractive and these other unextractable sub stances that are extraparietal. There are borderline substances, the classifica tion of which is still difficult.

Wide Variety of Extraneous Components

The extractives include a great va riety of organic components, some of which have been fully explored, and others which still remain to be identified. To even mention all types would be beyond the scope of this paper. Included in the list would be aliphatic, aromatic, alicyclic, hydrocarbons, alcohols, aldehydes, ketones, acids of all types, esters, ethers, and phenols. If we attempt a more specific grouping, then we must include a variety of carbohydrates, sterols, tannins, essential oils, resins, coloring matters, lignans, cyclitols, proteins, certain waxes, and some alkaloids.

Although, strictly speaking, the oleoresinous exudates of living trees are not extraneous materials of wood they, too, are sometimes included in discussions on wood extractives. No attempt will be made to cover these wide areas. This brief listing is given to contrast the relatively few cell-wall components with the many types of extraneous substances, and to emphasize the fact that the latter, rather than the former, serve to characterize the wood.

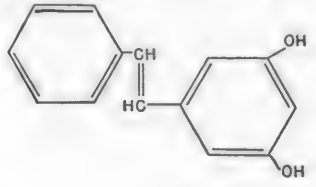
The Author: Dr. Louis E. Wise, now a Senior Research Associate, is a long-time member of the staff at the Institute of Paper Chemistry. He has contributed much to the field of wood chemistry.

[1] This paper was presented at the 133rd National Meeting of the American Chemical Society in San Francisco, Calif., April 1958.

[2] Numbers in parentheses refer to the Literature Cited at the end of this paper.

Extraneous Components and Wood Properties

If a wood possesses an agreeable r a foul odor, if it has a characteristic olor, if it manifests a marked re- stance to decay, if it shows a high urability in the face of attack by in- cts or marine fauna—we can ascribe



Pinosylvin

these properties to the extraneous com- ponents of the specific wood. If a wood is toxic and causes industrial hazards, if it shows unusual inflammability— extraneous components are the respon- sible agents.

An interesting tropical wood *(Ocotea rubra)* shows an exceptionally low rate of moisture absorption (1a) and this, too, may be due (in part at least) to the extraneous components in this wood, which is unusually high in chloroform-soluble, water-repellent waxy materials (2). It is common knowledge that the heartwood of pines is not pulped satisfactorily in the usual sulfite digestion, and that this same heartwood is quite durable. Both of these properties are accounted for by the presence of certain phenolic components, pinosylvin and its monomethyl ether, which are present sometimes to the extent of 0.8–1.0 per cent in the heartwood, but only in traces in the less durable sapwood, which can be pulped quite readily.

One can say, then, that the extraneous components serve to *fingerprint* the wood. Furthermore, the importance of the role played by some of these components is out of all proportion to their amounts present in the wood. The amounts of extraneous materials vary widely in different species, however. For example, the wood from a sugar maple yielded a total of less than 2.7 per cent extractives (3). In contrast to this, a quebracho wood *(Schinopsis lorentzii or S. balansae)*, a remarkable tannin-producer, yielded over 34 per cent extractives (4) removed by ethanol alone. These are extreme cases. Most of our native hardwoods and softwoods fall within these limits, and often approaching the lower rather than the higher limit. Analyses of other tropical woods also appear to remain within these two extremes.

The difficulty in removing all extractives is well-known. In extracting various woods with organic solvents, the fibrous residues (that is, the cell-wall components) are often far from white. This is especially noticeable in the case of a dark-colored wood like that of quebracho (just mentioned). Even when this was extracted exhaustively, the wood remained appreciably colored. Since the *color* of a wood is not contingent on the presence of cellulose or the hemicelluloses, and certainly only to a minor degree (if at all) on lignin, it is reasonable to assume that the extraction was incomplete, despite the fact that about 38 per cent of the weight of the original wood had been lost.

There are paradoxical cases in which an extractive (once removed and purified) is easily soluble in some neutral solvent, but cannot be completely extracted with this same solvent from the original wood. Pinosylvin in pine heartwood is an example. In the pure state, pinosylvin is very readily soluble in ether, but it can be removed only in traces from wood meal by ether (4a). A full explanation of this cannot be given, but the most probable is the one proposed by Holger Erdtman (5). There appear to be membranes in the original wood that are impervious to (and insoluble in) ether, and these block the leaching out of the pinosylvin. These "membranes" are themselves soluble in acetone or alcohol (in which pinosylvin is also soluble). Hence, an alcoholic extract of pine heartwood when evaporated and extracted with ether gives pinosylvin.

The distribution of extractives in the wood of an individual tree can vary widely. Often, at a specific height, variations across the bole will be surprisingly great. Extractives content may range from a low percentage in sapwood to one very high in certain areas of the heartwood. Wide variations may also be expected at different heights in the tree. For redwood, such fluctuations have been explored thoroughly by Kurth (6) and in the case of ponderosa pine, comprehensive studies have been carried out by Arthur Anderson (7), who also showed the effects of using various solvents (7a).

Even in a very small wood sample, the different botanical elements may show remarkable differences in their extractives content. For example, a sample of sprucewood, analyzed in its entirety may show as little as 0.9 to 2 per cent ether solubles, whereas wood rays isolated from this same sample may yield up to 15 per cent (or more) of this ether-soluble material, a fact that may have a marked industrial significance.

It may also be well to emphasize the fact that freshly felled (green) wood can show different properties towards an extracting medium than does seasoned or stored wood from the same species (8).

Extractives as an Aid to the Wood Anatomist

The wood anatomist can identify and characterize a genus by means of microscopic examination of a thin wood section. If he is lucky, he may also be able to identify the wood species, but this is certainly not always the case. In isolated instances, the chemist can be of help. For example, although slash pine wood and longleaf pine wood are morphologically similar, and although they both yield turpentines that are high in pinenes, that of slash pine is levorotatory and that of long leaf pine is dextrorotatory (9).

Jack pine wood and lodgepole pine wood may be very difficult to tell apart under the microscope, but their turpentines can be easily differentiated. That of jack pine contains almost exclusively a turpentine composed of the pinenes (9). That of lodgepole pine contains over 90 per cent phellandrene and only traces of the pinenes (10).

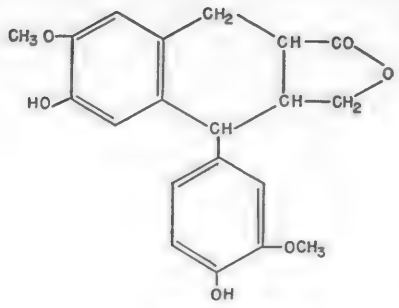
It may be difficult to distinguish between ponderosa pine and jeffrey pine, but their turpentines are certainly very different. Jeffrey pine wood contains appreciable amounts of *n*-heptane (11) and small but characteristic amounts of aliphatic aldehydes. Ponderosa pine wood, besides containing variable amounts of pinene (usually beta) and other volatile components, is characterized by significant amounts of Δ^3-carene (12).

The dream of the chemist interested in wood has been to find a chemical differentiating key, based on the extraneous components, but this key is for the remote future.

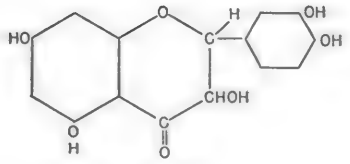
Industrial Uses

Industrial by-products, for which extraneous components are the precursors, are so well-known and have been so excellently reviewed by Dr. Arthur Anderson (13) that they require only fleeting mention. The very components that can be extracted from pine wood by ether give rise to tall oil in the kraft cook. This oil contains the resins, the fatty acids, and sterols. The kraft industry also yields as a by-product "sulfate turpentine", the forerunner of which is the essential oil originally present in the wood. This product represents nearly 25 per cent of the turpentine production of the U. S.

Pine stumpwood (the "lightwood" of the South) gives rise to wood rosin and certain volatile oils (including pine oil) that form the basis of a number of industrial products. Despite the twilight of the natural dyes, a few woods still furnish certain dyestuffs (like "old fustic" and logwood). Certain woods (like the quebracho mentioned earlier) yield important tannins.



l-Conidendrin



Douglas fir flavanone (Taxifolin)

American chestnut wood (despite the demise of the trees) still serves as an important source of tannin. Eastern red cedar wood *(Juniperus virginiana)* when steam distilled gives an essential oil rich in sesquiterpenes that is used in microscopy, in soaps, and in perfumes. There are many other by-products, the potential commercial values of which have been or are being explored. Among them are conidendrin (13a) and taxifolin (13b). The great variety of the extractives make this an area which is challenging both to the chemist and to the man interested in marketing research.

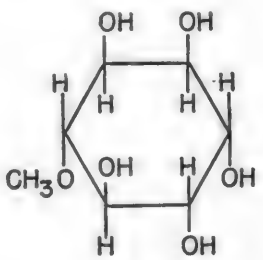
Pioneers in the Extractives Field

Fundamental studies in the extractives field have not been limited to one country or one laboratory, and of the many investigations only a limited number can be mentioned. This is also true of the investigators. Some of them have been primarily organic chemists, interested in the identification and structures of some very intriguing organic compounds that happen to be present in wood. Others have been interested mainly in analytical techniques and in the distribution of the extractives. Still others have seen the important taxonomic implications in their studies, and certain others have shown such wide interests that they have contributed in all of these fields and have also kept a weather eye on the utilization of the extractives.

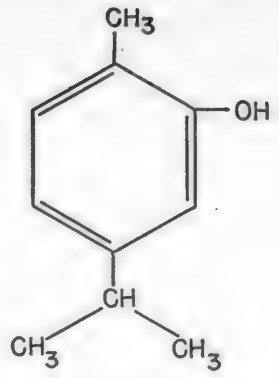
To this last-named group of generalists belongs Arthur Anderson of the University of California. He has elucidated the structure of pinitol (from sugar pine) and has been interested in its possible commercial value (14, 15). He has isolated arabinose from Port Orford cedar heartwood (16) and (with Kritchevsky) (17) has helped in a study of the components of the essential oil in its stumpwood, thus dealing quantitatively with 18 individual compounds. With Wadman and Hassid (18) he elucidated the structural units of an arabogalactan isolated from Jeffrey pine, and with Zavarin (19) he showed the presence of carvacrol, hydrothymoquinone, *p*-methoxythymol, and *p*-methoxycarvacrol in incense cedar as well as the occurrence of libocedrol and its complex-formation with methoxythymol. These are just a few of his contributions to the extractives of various Western woods.

Another important researcher is Ervin Kurth, whose work on redwood (6) and Douglas-fir (20) extractives and whose analytical techniques and ingenious methods of isolation and identification are well-known. J. C. Pew of the U. S. Forest Products Laboratory has carried out significant studies on extractives from Douglas-fir (21), on membranous substances in various heartwoods (22), and on the extractives in black cherry wood (21). George Harris (23) and his colleague Sanderson (24) have done exceedingly important work in elucidating the constitution of resin acids, after devising ingenious methods for their isolation, purification, and analysis. Brilliant pioneering work in this area was done by Leopold Ruzicka and coworkers (24a). Adams (25) and Bishop (26) in Canada have contributed in the area of the water-soluble arabogalactans, isolated respectively from white spruce wood and from jack pine. Extractives of this general type have intrigued chemists interested in carbohydrates for many years. Gardner (26a) and various colleagues in Canada have carried out important studies on the tropolone derivatives of Western red cedar, some of which have had distinct practical significance.

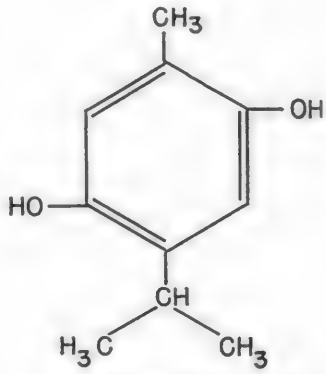
A pioneer in the lignin field is Dr. R. D. Haworth of the University of Sheffield (27). The wide distribution of these extractives may be gaged from the resumé of Hearon and McGregor (28).



Pinitol



Carvacrol

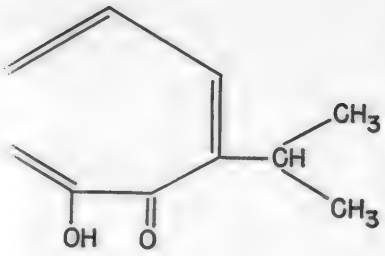


Hydrothymoquinone

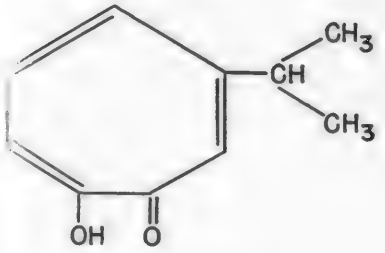
Holger Erdtman, the Swedish chemist to whom reference has already been made, has catalyzed the entire field of wood chemistry. His own researches on pinosylvin and its ethers, on the thujaplicins of Western red cedar, on many of the phenolic bodies in pine heartwood, and his emphasis on the taxonomic importance of these compounds are classical (29). A worthy colleague of Erdtman is Lindstedt (30), who is continuing much of Erdtman's work at the same high level.

Among the pioneer workers on essential oils obtained from woods or the oleoresins from the living tree are A. W. Schorger (31) in the United States and the late Sir John Simonsen of Great Britain, whose studies on the terpenes of Indian pines are outstanding (32). At present, actively occupied with gum turpentines of the entire world is N. T. Mirov (33), who has advanced our knowledge on the essential oils of pines and shown their relationship to dendrology and genetics.

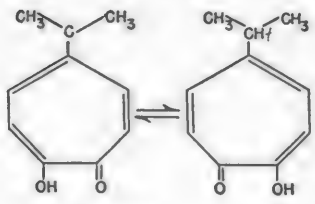
Finally, when we consider the extractives of certain rare tropical hardwoods, Dr. F. E. King (formerly at the University of Nottingham) (34) and his able co-workers must be given an accolade. Interesting hardwood samples were gathered from Africa, South America, and Asia from which King and his colleagues isolated a great va-



) α– Thujaplicin



β – Thujaplicin



γ-Thujaplicin

riety of extraneous components, which they purified and characterized and whose structure they determined. The diversity of King's interests may be gaged when we note that he explored complex di- and triterpenes (35), flavones (36) and isoflavones (37), cyclitols (38), chalcones (39). steroids (38), and a complex stilbene (40), to give only a partial listing.

It is only fair to state that other laboratories and other workers in the United States, England, Germany, France, Japan, Sweden, Austria, Finland, and the U.S.S.R. have made sound contributions that cannot be included in this panoramic survey.

Future Studies

When it comes to future studies on the wood extractives, the question may well be asked, "Where should research efforts be directed?" The extraneous materials of our native coniferous woods have been explored far more fully than have those of our hardwoods, which are coming more and more into the industrial chemical picture. The feeling here is that the area of exploration lies with these hardwoods. True, certain tropical hardwoods have been studied intensively and brilliantly by F. E. King and by others, but usually these have been exotic species. Some of the everyday hardwoods of the temperate zone deserve similar attention at the hands of equally enthusiastic chemists. Some of the researchers at Appleton are now exploring this terrain.

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Fermenting Wood Substrates

WITH A RUMEN CELLULOLYTIC BACTERIUM[1]

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Although aspen and ash were fermented without pre-treatment, other woods were rendered fermentable by milling, alkali cooking, and predigestion. Softwoods were generally less fermentable than hardwoods.

The FPL of C "Mechanical Cow", constructed in an effort to duplic e in the laboratory fermentation conditions present in the live animal.

WHAT THIS RESEARCH MEANS

One approach to gainful utilization of wood residues is to ferment the carbohydrate fraction of the residue by means of suitable microorganisms, and then to recover the products of fermentation for market. With this approach at least two points of view are currently held. The one involves acid hydrolysis of the wood residues to wood sugars with subsequent fermentation to any of a number of useful products. Such a process must compete favorably with sugars obtained from agricultural sources—sugar beet, sugar cane, molasses—and requires expensive, acid-resistant equipment. The other point of view involves use of specific organisms capable of fermenting wood residues directly or after very mild treatment to produce useful end products.

This paper represents an initial study based on the latter view. Since rumen organisms are used as the agents to bring about fermentation, two possibilities for utilization of wood residues arise. Firstly, research resulting in complete utilization of the carbohydrate fraction could lead to an industrial fermentation of wood residues to produce useful chemicals. Secondly, wood residues capable of fermentation by these organisms could be incorporated as a major adjunct of cattle feed.

The problems involved are many and varied, but it is anticipated that extensive basic research in this field will eventually result in a suitable process for utilizing wood waste residues by fermentation to the benefit of the wood industries as a whole.

THE OTTAWA LABORATORY of the Forest Products Laboratories of Canada, has long been interested in the problems pertinent to the practical and economic utilization of wood waste or residues. Developments in recent years have resulted in increasing quantities of these wood residues being turned to profitable use, particularly in the form of pulp chips. Much of this wood substance remains unused, however, and there is urgent need for the development of new means of gainful utilization.

Wood waste contains considerable amounts of potentially fermentable material, and some attempts to utilize such material fermentatively have been made (1, 2). A further study in this direction is reported herein. In this study, an attempt has been made to determine the fermentability of various wood species, the beneficial effect of some pre-treatments, and the factors that inhibit fermentation. A rumen cellulose decomposing organism was used to test both treated and untreated wood for usefulness as substrate material.

The test organism used was isolated from the paunch ingesta of cattle. In the host, these organisms live in close relationship with the animal within which they exist under ideal conditions. When an attempt was made to duplicate these conditions in *in vitro* studies, rapid degradation of cellulose was observed, which suggests that wood waste substances might be utilized similarly to advantage (3). However, in the absence of ideal fermentation conditions, that is, batch fermentations in a flask or test tube, only media of low substrate concentration (0.5g. contained in 100 ml.) were completely fermented and, therefore, the end-product concentration was extremely limited. An effective and rapid test for a large number of substrates, as contemplated in this study, required a sensitive batch method. Two such methods were developed. The findings from use of these methods and an evaluation of the data obtained are reported herein.

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[2] The Forest Products Laboratories of Canada are a division of the Forestry Branch, Department of Northern Affairs and National Resources.

[3] Numbers in parentheses refer to the Literature Cited at the end of this paper.

Materials

Rumen Fluid: All growth-factor requirements were added to culture media in the form of rumen fluid obtained directly from a freshly slaughtered animal. Rumen fluid so obtained was refrigerated until required. Just prior to use, all heavy material was removed by centrifuging at 26,000 rpm for a period of 30 minutes. Rumen fluid supported more rapid growth than any other nutrient tried.

Substrates: Whatman No. 1 filter paper was generally used where cellulose was required, that is, in control cultures. When cotton was employed, medical absorbent cotton was used, but it was first dewaxed by alcohol-benzene (1:2) extraction (4), and then cut into short lengths. Various wood species used for test were ground to wood meal in a Wiley mill. Other treatments were used as designated in the text. The wood species used were as follows: white pine, *Pinus Strobus* L.; red pine, *Pinus resinosa* Ait.; eastern larch, *Larix laricina* (Du Roi) K. Koch; Douglas fir, *Pseudolsuga* taxifolia (Poir.) Britton; western larch, *Larix occidentalis* Nutt.; black spruce, *Picea mariana* (Mill.) B.S.P.; aspen, *Populus tremuloides* Michx.; black ash, *Fraxinus nigra* Marsh.; white elm, *Ulnus americana* L.; basswood, *Tilia americana* L.; white birch, *Betula papyrifera* Marsh.; yellow birch, *Betula lutea* Michx f.

Test Organism: The organism used for study was isolated from fresh rumen fluid by a method developed by the author (5). The organism has been designated 14A (for purposes of this Laboratory). All data indicate that this organism is identical with *Ruminococcus flavefaciens* isolated by A. Kaars Sijpesteijn (6). This organism produces succinic acid as the main fermentation end product, and a small amount of formic acid. For stock culture use the organism was freeze-dried, but inoculum for tests was prepared in 80 percent (by volume) rumen fluid broth. Transfers were made approximately two weeks apart to ensure an active culture. The volume of inoculum was varied for individual experiments.

Warburg Test Method Experiments

In this method, test substrates were placed into conventional Warburg flasks along with an active suspension, the change in manometer levels was observed over an 80-minute incubation period, the curves were plotted, and differences in slope were compared. Carbon dioxide measured was produced from two sources: metabolic carbon dioxide and that released by the action of fermentation acids on the bicarbonate buffer system.

Some difficulty was at first experienced in obtaining an active suspension. However, a suitable suspension was achieved in the following manner. Two hundred milliliters of medium containing 50 percent rumen fluid and 1 percent fructose with salt, buffer, and reducing agent as described elsewhere (5) was prepared in a round-bottom flask and inoculated with one milliliter of an active test culture and left to incubate 42 hours at 40° C. with intermittent manual shaking. The cells produced were recovered from the medium by centrifuging at 26,000 rpm for 30 minutes in a high-speed, refrigerated centrifuge.

Care was taken to maintain anaerobiosis throughout transfer of the cells to centrifuge tubes and throughout all manipulations following. Supernatant material was drained off and a wash solution (normal medium without rumen fluid) was used to resuspend the cells. The cells were again thrown down, and the supernatant liquid was poured off. Cells from all centrifuge tubes were combined and suspended in 25 to 40 ml. of fresh wash solution and refrigerated (capped) until required. Suspensions prepared in this manner were consistently active. Cells could be grown with cellobiose, but preparations with fructose were more active.

A routine procedure was established where substrate, make-up water, and rumen nutrient were added to the test flasks first, followed by the buffer previously gassed out and fortified with reducing agent. Finally the cell suspension was added and the whole apparatus readied for the experiment. Most insoluble substrates, such as wood, celluloses, and so forth, were weighed into the test flasks, (0.1–0.4g.), but pulp suspensions were added by pipette. One milliliter of remen fluid per flask supplied all the essential nutrients. Water was added to bring the total volume to 5 ml. per flask. A buffer solution was prepared by mixing 25 ml. of Hungate's salt solution, 25 ml. of Hungate's phospate solution, 0.15g. sodium bicarbonate, and 0.25g. of sodium thioglycolate. (The Hungate solutions were 10 times as concentrated as used by Hungate (7)). One ml. of this buffer was added to each flask.

Each flask was then placed on a manometer and shaken in the water bath at 40° C. and gassed with oxygen-free carbon dioxide. After 10 minuutes each manometer in turn was removed from the machine, the flask quickly slipped off, two milliliters of cell suspension added, and the flask replaced on the manometer and shaken for another 15 minutes. During this manipulation, gassing was continued. The manometers were then adjusted to the 5 mm. mark, and the cocks and vents were closed. Sporadic rises in manometer levels were recorded soon after the manometers were closed off. This was eliminated if the manometers were reset to the 15 mm. mark after a second 15 minute equilibration period. Suitable controls were run with each experiment. Very little gas production was observed from the suspensions where no substrate had been added. Any values obtained were subtracted from the test flask readings. Useful data were obtained during 80 minute incubation periods.

By means of the procedure described, several runs were tried to determine the substrate value of various substances. Fig. 1 shows in graph form the data obtained. The dotted-line curves were included to show the effect produced by use of a heavier suspension (approximately twice that for the other curves). If the slopes of Curve A_1 and A, and C_1 and C are compared, a greater difference is observed for untreated straw than for fully pulped cellulose. This may indicate that untreated materials may be more readily attacked if large populations are present to overcome natural inhibitory factors.

A comparison of curve C with B shows the beneficial effect of treating straw with alkali. Straw was steeped in 5 percent sodium hydroxide for 18 hours at room temperature, then washed thoroughly with water, dried, and used for test. The treated straw was utilized almost as well as high alpha pulp (Curve A). In the same experiment, Douglas-fir sawdust was treated in various ways and the effects of treatment compared. In one case, Douglas-fir sawdust was partially pulped with sodium chlorite. One gram of wood was treated in a pressure bottle with 0.6 gm. sodium chlorite and 10 ml. of a 50 percent acetic acid solution for one hour at 80° C. The treated wood was washed throughly and dried.

In another case, Douglas-fir was ball-milled both in the presence and absence of dimethylformamide (DMF), a swelling agent. The latter was removed and the treated wood compared by means of the Warburg procedure. Curves F and D show the effect of these treatments compared with untreated fir (Curve C), high alpha pulp (Curve A), and dewaxed cotton (Curve E). Ball milling had a beneficial effect, but milling in the presence of DMF had no effect. Partial pulping apparently had a greater effect than ball milling, but did not result in activity so rapid as achieved with high alpha pulp.

The low level of activity recorded for dewaxed cotton (Curve E) compared with high alpha pulp (Curve A) was interesting to observe. Both are high in alpha cellulose, but the pulp has a lower DP (16), which indicates that low DP may be required for rapid utilization of cellulose. Further investigation by the Warburg method was not undertaken at this time, since there was some fear that the heavy suspension used possibly did not give a true indication of wood fermentability.

Culture Test Method Experiments

A second method of test was devised in which test substrates were placed in test tubes, inoculated medium was added, and the tubes were left to incubate. The succinic acid produced by fermentation was extracted and separated by paper chromatography, and the concentration was compared with that obtained from filter-paper substrate. Under these conditions of test, succinic acid (the measure of activity) could only be produced when the small inocula used gave rise to rapid (logarithmic) growth of cells. This was in contrast to the heavy pregrown cell suspensions used for Warburg studies. In other words, a heavy suspension of cells may show activity on a wood substrate, but a few cells of the same culture might not be able to use wood as a substrate to grow and multiply on.

A standard procedure was employed for all tests. Rumen fluid medium (50 percent by volume) was prepared with the salt concentrations and by the technique described by Hungate and as modified by the author (5). Materials (0.1–0.2g.) for test were added to 22 by 175 mm. culture tubes, wetted with one milliliter of water, and then sterilized. Sterile medium inoculated with test culture (1 percent by volume) was then distributed (20 ml.) to all culture tubes containing the sterile test materials. Anaerobic techniques was strictly observed at all times. Tubes were well mixed and then allowed to incubate at 40° C. for one week with intermittent manual shaking.

Culture tubes were then removed from the incubator ,and the succinic acid produced was measured. To remove interfering substances, all fermented media were cleared with zinc hydroxide, according to the method of Neish (8). Precipitated material was centrifuged off, and the supernatant liquid (10 ml.) was acidified and then ether-extracted for 4 to 5 hours, in small extractors (8). The extracted material was treated with excess diethylamine and then evaporated to dryness under vacuum at room temperature. The dried material was redissolved in 0.2 ml. of 95 percent ethanol. The resulting solution was used to spot chromatograms; 2 μl. were used for each of 4 spottings. Spots were applied by means of a micro syringe (1 ml.) as described by Neish (8). No. 1 Whatman paper 22 by 6 inches was used as the stationary phase, and chromatograms were developed in 8: 1:1 (95 percent ethanol: NH_4OH:H_2O) for approximately 18 hours. The diethylamine salts of the acids were identified by dipping the papers in either ninhydrin (9), or Bromphenol blue (9). A control with filter paper as substrate was run with all tests, and the succinic acid produced was chromatographed. The intensity of the control spot obtained was arbitrarily given the rating +4. All test material showed either the same intensity or less, and was designated accordingly. Formic acid production was not a good measure of activity for two reasons. Less of this acid was produced, and formic acid was not well separated from acetic acid on chromatograms. Since there was no succinic acid in the unfermented medium and chromatographically it separated well from other acids present (butyric, acetic and formic acids), it provided a very suitable measure of bacterial activity.

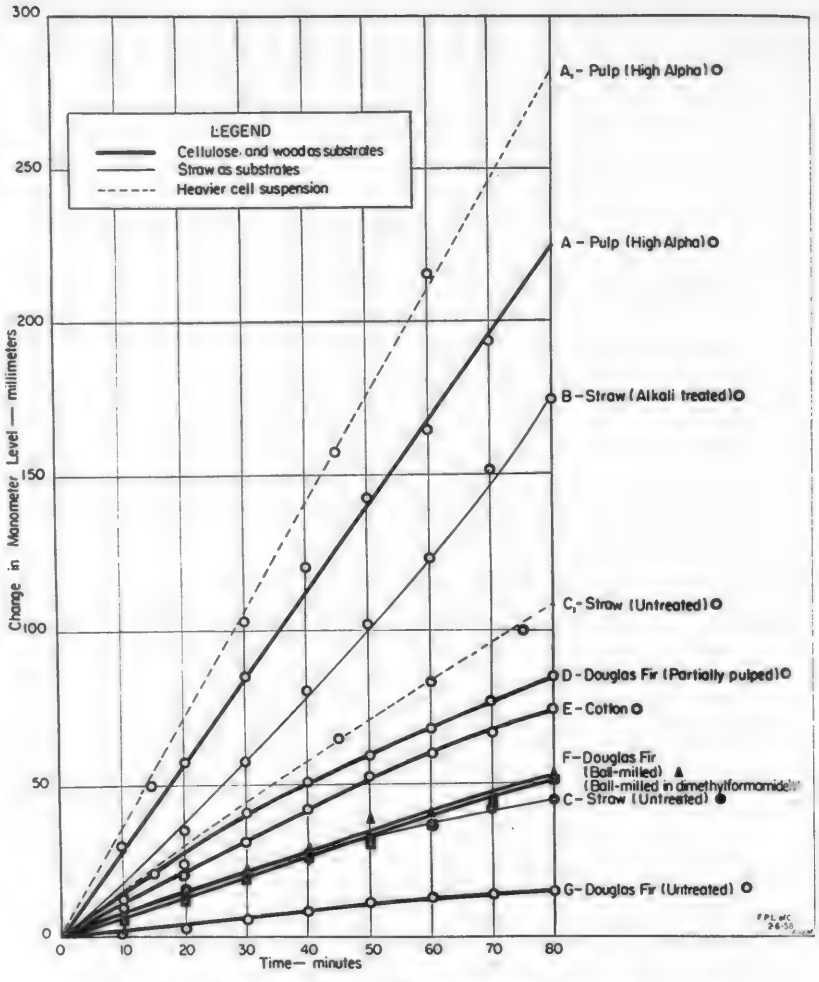

Fig. 1.—Effect on fermentability of pre-treatment of various substrates tested by the Warburg method.

Since Warburg studies had shown fine grinding treatment to be beneficial, finely ground wood was tested by the culture method. Various woods were ground in the ball mill while others were powdered by means of very fine (No. 320A) emery paper. These treated woods were tested and then compared with untreated woods. The results obtained are shown in Table 1.

Table 1.—EFFECT OF FINE GRINDING ON THE FERMENTABILITY OF WOOD SUBSTRATES

(Units represent succinic acid production where +4 is a maximum)

Substrate	Untreated	Material obtained by-ball-milling	Materi obtain by sandin
No. 1 Whatman filter paper	+4	---	---
Cotton	+2	---	---
Douglas-fir	Trace	+1	---
Black spruce	Trace	---	+2
Western larch	Trace	---	+2
Aspen	+3	+3	+3
Black ash	+3	---	+3
White elm	Trace	+4	---
Basswood	Trace	---	+3
White birch	Trace	+4	+4

Table 2.—EFFECT OF CHEMICAL TREATMENT ON THE FERMENTABILITY OF WOOD SUBSTRATES

(Units represent succinic acid production where +4 is a maximum)

Substrate	Untreated	Alkali cook	Acid cook	Water cook	Swollen[1]
Douglas-fir	Trace	Trace	None	-----	-----
White pine	Trace	+1	-----	Trace	-----
Western larch	Trace	Trace	-----	Trace	-----
Aspen	+3	+3	Trace	+2	Trace
Black ash	+2	+4	-----	+2	-----
White elm	Trace	+3	-----	Trace	-----
Basswood	Trace	+4	-----	Trace	-----
White birch	Trace	+4	-----	+2	-----

[1]Two samples, one swollen in 38% urea the other in DMF.

Table 3.—EFFECT OF PREDIGESTION WITH WOOD-ROTTING FUNGI ON THE FERMENTABILITY OF WOOD SUBSTRATES

(Units represent succinic acid production where +4 is maximum)

Substrate	Untreated	Vanaria effuscata (white rot)	Unidentified (white rot) B-312	Peniophora (white rot) B-285	Trametes serialis (brown rot)	Polyporus immitis (brown rot)
Red pine	None	+2	---	+1	None	---
Yellow birch	None	+2	+2	---	----	None

Aspen and black ash fermented without any prior treatment, although not as well as filter paper. Fine grinding failed to further improve these woods as substrates. The other woods shown were all rendered more fermentable by fine grinding; elm and birch fermented as well as filter paper. The coniferous woods were least affected by treatment.

The data for white birch indicate that ball milling and sanding are equally efficient in rendering the wood fermentable. The figures obtained for cotton and filter-paper cellulose by the culture method are similar to results observed for cotton and high alpha pulp by the Warburg method. Again, the difference in DP between these materials probably explains the lower figure for cotton cellulose.

Several experiments were tried where wood was cooked under pressure in the presence of alkali, acid, and plain water as a means to render them fermentable. Treatment with swelling agents was also tried. Wood was cooked with 1–5 percent sodium hydroxide solution (1:5 wt./vol.) in pressure bombs held at 150° C. in an oil bath. Cooks with hydrochloric acid and water were carried out in the same manner. All cooks were left for 1 hour, after which the temperature was lowered and the wood washed thoroughly with water and dried. Aspen sawdust was swollen in 38 percent urea as well as in DMF. Both swelling agents were removed with water and the woods were tested while wet. All the treated wood and untreated controls were made up into test media by means of the culture method procedure. The results obtained are shown in Table 2.

Alkali cooking apparently had a beneficial effect, especially with the deciduous woods, elm, basswood, and birch. Only a limited effect was observed for Douglas fir and pine, while larch was not affected at all. Acid cooking had a detrimental effect as can be seen clearly in the case of aspen, which fermented without pre-treatment but showed no reaction after acid cooking. The same was observed for swelling treatments. Aspen again showed no reaction. Cooking with water only helped in the case of birch, but did not have so much effect as an alkali cook.

Another type of pre-treatment was tried, namely digestion with wood-rotting fungi. Pine and birch were subjected to rot by the soil block method (10). The wood blocks were incubated approximately six months, then lifted from the soil, the mycelia mats scraped off, and the blocks reduced to shreds with a coarse rasp. This fungally digested wood was then subjected to test by the culture method. The data obtained are reported in Table 3. White-rot treatment had a limited beneficial effect, but brown rots failed to show any helpful effect. In no case was the effect observed as great as for fine grinding or alkali cooking.

The foregoing tests show only that various wood species were fermented, but they failed to show what fraction of the wood holocellulose fermented. Further tests were therefore undertaken to determine—for the woods tested—whether the alpha cellulose, the hemicellulose, or both fermented. In a first experiment, Douglas fir, spruce, and aspen were fully pulped by treatment with sodium chlorite (11), and the holocelluloses were fractionated to yield alpha and hemicelluloses (12). These two fractions were then tested as substrates by the culture method. The results, tabulated in Table 4, show that the alpha cellulose of all three woods fermented as did the hemicellulose of aspen. The hemicelluloses of Douglas fir and spruce were only partly fermented. Since both fractions extracted from the whole wood of aspen were fermentable, an attempt was made to determine if both fractions fermented as combined with lignin in the whole wood. The principle applied was to ferment a quantity of wood just sufficient to allow almost complete fermentation of the holocellulose fraction. By comparing the hydrolysates of an unfermented control and the fermented material by means of paper chromatography, loss in glucose (from cellulose) and xylose (from hemicellulose) shows which fraction of the wood is utilized by fermentation.

Table 4.—FERMENTABILITY OF WOOD HOLOCELLULOSE FRACTIONS

(Units represent succinic acid production where +4 is maximum)

Substrate	Alpha cellulose	Hemicellulose
Douglas-fir	+4	+1
Black spruce	+4	+1
Aspen	+3	+4

Ball-milled aspen as well as ball-milled birch were added to 150 ml. batches of 50 percent rumen fluid medium contained in 250 ml. round bottom flasks. To facilitate the use of pipettes, ground wood was first weighed (0.5g.) into an aliquot of water and stirred well, and the heavier particles were allowed to settle out for a few minutes. The resulting suspensions were then added to media, taking care not to include the heavier material. The media were sterilized, cooled, and inoculated with 0.5 ml. of test culture. For prefermentation analysis, 30 ml. aliquots were withdrawn and refrigerated until required. Fermentation was allowed to proceed for one week, after which the flasks were removed from the incubator. Twenty-five milliliter aliquots were then taken from both the refrigerated media and the incubated media, placed into beakers, and the whole brought to dryness at 105° C. The dried residues were hydrolyzed by the method of Saeman and others (13). Each hydrolysate was passed over 50 ml. of wet Amberlite IR–4B resin with washing. The eluate and washings were combined and then brought to dryness under vacuum at 40° C.

Sugars were extracted from the dried material with redistilled pyridine (9). Pyridine was evaporated, and the residue was solubilized with 2 ml. water. Exactly 12 μl. of the latter was used to spot No. 1 Whatman paper strips for chromatography. A one-milliliter syringe fitted with a micrometer screw was used for the spotting (8). Chromatograms were run by the descending technique, and 3:1:3 (ethyl acetate: acetic acid: water) was used as the developing solvent. Sugars were identified with aniline phthalate spray (9). A typical chromatogram that compares poplar and birch before and after fermentation is shown in Fig. 2. It is immediately apparent that both glucose (alpha cellulose) and xylose (hemicellulose) were consumed during fermentation. Both fractions of both woods appeared to ferment equally well, which indicates that *in situ* holo-

celluloses of aspen and birch are fermentable.

In the course of this investigation, some preliminary data were collected that might suggest the mechanism by which this organism breaks down holocelluloses. A number of sugar compounds, some suspected as intermediates in the breakdown of holocellulose, were tested for their ability to support growth. These substances were weighed (0.1g.) into culture tubes, one milliliter of water was added, and the tubes were plugged with cotton and sterilized. The culture method of test described was then followed. The turbidity of the media compared to a water control was indicative of growth. Smears were made and succinic acid analysis was also carried out in most cases. The results obtained are shown in Table 5.

Table 5.—FERMENTABILITY OF VARIOUS SUBSTRATES, SOME OF WHICH ARE POSSIBLE INTERMEDIATES IN THE BREAKDOWN OF CELLULOSE

(Units represent succinic acid production where + 4 is maximum)

Substrate	Turbidity	Smear test	Succinic acid
Water (control)	0	0	---
Cellulose	Max	+	+4
Starch	0	0	---
Xylan (barley)	Max.	+	+4
Xylan (wheat)	Max.	+	+4
Cellobiose	Max.	+	+4
Sucrose	½ Max.	+	---
Glucose	0	0	---
Mannose	Slight	+	Trace
Galactose	0	0	---
Fructose	Max.	+	+4
Arabinose	0	0	---
Xylose	0	0	0
Xylulose[1]	Slight	+	Trace
Mannitol	0	0	0
Sorbitol	0	0	0

[1]Approximately .01 g. Xylulose/20 ml. medium.

The organism grew well with cellulose, xylans (14), cellobiose, and fructose. Approximately half of this growth was obtained with sucrose. Probably only the fructose half of the sucrose molecule was fermented. Xylulose (ketoxylose) also showed some growth response. The amount of xylulose obtainable for test was limited to approximately 0.01g., however. Tests with a higher concentration of xylulose are expected to show good growth. If this is true, one would suspect breakdown of higher molecules (cellulose, xylan, and so forth) to involve keto-sugars. On the other hand, cellobiose contains no keto-sugar and yet supports growth extremely well. It is noteworthy that glucose does not support growth at all. Mannose showed a limited response.

Discussion

Both procedures for testing the fermentability of wood species, 1) the Warburg method and 2) the culture method used in this investigation, are rapid and sensitive. Probably the culture method is the better method for a preliminary study such as this because of its ease and simplicity. Many materials could be tested for substrate usefulness in a very short time. Since all observed activity is the direct result of growth from small volumes of inoculum, positive results indicate that the material under test would be suitable for advanced fermentation study. The Warburg method is somewhat more sensitive and probably is the better method where closely allied substrate preparations are to be tested for maximum activity, and where rates of substrate utilization are to be studied.

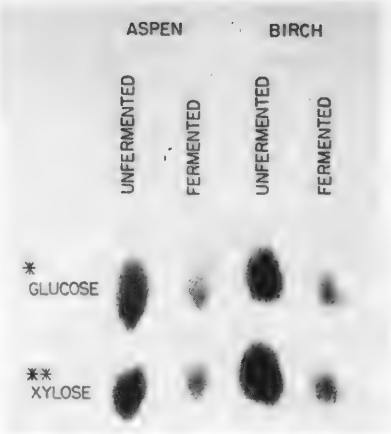

Fig. 2.—Chromatogram showing utilization of cellulose and hemicellulose of aspen and birch by the rumen test organism.

*** Represents cellulose, acid hydrolysis of which yields glucose.**

**** Represents hemicellulose, acid hydrolysis of which yields xylose.**

Regardless of the method used, the beneficial effect of pretreating wood substrates by milling, alkali cooking, and prefungal digestion were demonstrated. From the type of data obtained, it is difficult to determine how wood is affected by treatment so that it becomes fermentable. Both methods show that cotton is utilized to a lesser degree than high alpha pulp. Since cotton and high alpha pulp differ mainly with respect to DP, a reduction in chain length could possibly be one factor involved in rendering wood fermentable.

Native woods are reported to have an average DP of 5,000 (15). Ott and others (16) point out that cotton treated in a ball mill has a lower DP caused by mechanical cleavage of primary valence bonds during milling. It is reasonable to suppose that the DP of cellulose in native woods is also reduced by ball mill treatment.

Rumen organisms were shown to decompose wood irradiated with high energy cathode rays (17). Further study has shown that such treatment results in depolymerization (18). Similarly, alkali treatment (1 to 5 percent), found to be of benefit, could lower DP. Air oxidation during alkali cooking effectively splits beta-glucosidic linkages (16). Such alkali treatment would cause very little pulping action, so that the effect observed was probably due to a reduction in DP. The cellulases of wood-rotting fungi are reported to break down the large cellulose molecule by random cleavage (19). Conceivably the effect produced in woods in this study by white-rot fungi is similar and results in a lower DP. Although many data suggest that high DP is the prime factor that inhibits bacterial utilization of wood substrates, it is difficult to explain why acid treatment in this study rendered aspen unfermentable, especially when untreated aspen was found to ferment well.

Hajny and others (1) obtained some inhibition of bacterial activity with acid-treated cellulose, and suggest that toxic substances may have been produced. However, they found acid-treated woods were more fermentable than untreated woods. They considered that decomposition took place by a gradual reduction of chain length—the action taking place at the ends of the chain. Much more study is required before definite conclusions can be drawn. It would seem reasonable, however, that DP is at least one factor that the organism has to surmount before fermentation can proceed.

High lignin concentration and the ligno-cellulose bond have both been held responsible for inhibiting fermentative action (17, 20). The results of this investigation lend support to both views. Generally, coniferous woods were less affected by the treatments tried than deciduous woods. However, pine was shown to ferment in part after treatment with white-rot fungi. Although no lignin determinations were made, it is generally assumed that lignin is largely consumed, thus leaving a cellulose residue. Since the latter ferments, removal of lignin would appear to be of import. Warburg studies have shown that partially pulped Douglas-fir was more effectively attacked than ball-mill-treated Douglas-fir, which indicates that lignin removal is of consequence. Conversely, all ball-mill-treated woods retain their original lignin content, although the lignin may be somewhat changed by treatment; yet in many cases they fermented well. If lignin is responsible for the inhibition of fermentations, the beneficial effect produced by ball-milling may be due to some change in the structure or linkage of the lignin.

Substrate accessibility, the ratio of amorphous cellulose to crystalline cellulose, and the degree of swelling are all phenomena possibly concerned with the fermentability of wood. Ball-mill treatment is said to convert crystalline cellulose to the amorphous state (16).

At the same time, a high proportion of substrate surface area becomes exposed. These factors may be responsible at least in part for the effect observed with ball-mill-treated wood. The few swelling agents tried as means to render wood fermentable were shown to be detrimental. This is rather difficult to explain, unless small traces of swelling agent remained in the wood and were toxic to the organism. However, the urea used in one test would hardly be toxic. Some other physical factor must be involved.

The alpha and hemicelluloses of aspen and birch *in situ* were fermented by the test organism. This result was particularly encouraging, since these fractions represent the major carbohydrate fraction of these woods. Isolated hemicellulose fractions of fir and spruce did not ferment well. A suitable explanation for this is lacking unless the higher mannan content of coniferous hemicelluloses is in some way responsible. In any case, the alpha cellulose of both the coniferous and deciduous woods tested was readily fermented.

Yield studies are not included in this investigation. Such tests would require either the use of a mechanical system similar to the *in vivo* rumen enviroment, or a feeding study employing treated wood and live animals. The latter may possibly be the easier approach, since a system designed to remove fermentation end-products and leave nutrient essentials untouched is difficult to design. It is anticipated that some such study will be undertaken. Until such time, the true value of any pre-treatment, the suitability of particular species as substrate, and the economic aspects entailing the use of any particular rumen organism will be in doubt.

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MAKING GLUE GO FURTHER:

Mechanized Foaming of Adhesives[1]

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Though foamed adhesives will not revolutionize the field, better coverage, easier spread control, less wastage, and possibility of bonding extremely porous material are impressive.

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NEW DEVELOPMENTS IN WOOD adhesives have come in rapid succession since World War II. Many synthetic materials have been developed or adapted to adhesive use to supplement long-used natural adhesives such as animal glues, proteins, starches, gums, and so forth. These rapid strides have been responsible in large part for many glued products in common use today.

In plywood, the use of synthetic phenol-formaldehyde resin has added exterior durability and thus greatly increased the range of plywood applications. The use of other synthetic materials, such as urea-formaldehyde resin, has increased the water resistance of numerous products, such as hardwood plywood, fiberboard containers, and doors—again greatly increasing the range of possible applications. It would be a simple matter to list many other products that would not enjoy the wide application they do today if it were not for developments in the field of adhesives.

A wood adhesive is not a simple thing. It is generally a special combination of the basic bonding agent with extenders, fillers, chemicals, and thickeners designed to give each adhesive the specific characteristics needed for a particular gluing job. For some applications, the choice of the correct extender or filler, to increase bulk and reduce penetration, can be almost as important as the choice of the bonding agent itself. Even protein glues such as blood, soya flour, or casein contain an extender in the form of water. In addition to water, many solid fillers such as wood flour, wheat flour, shell

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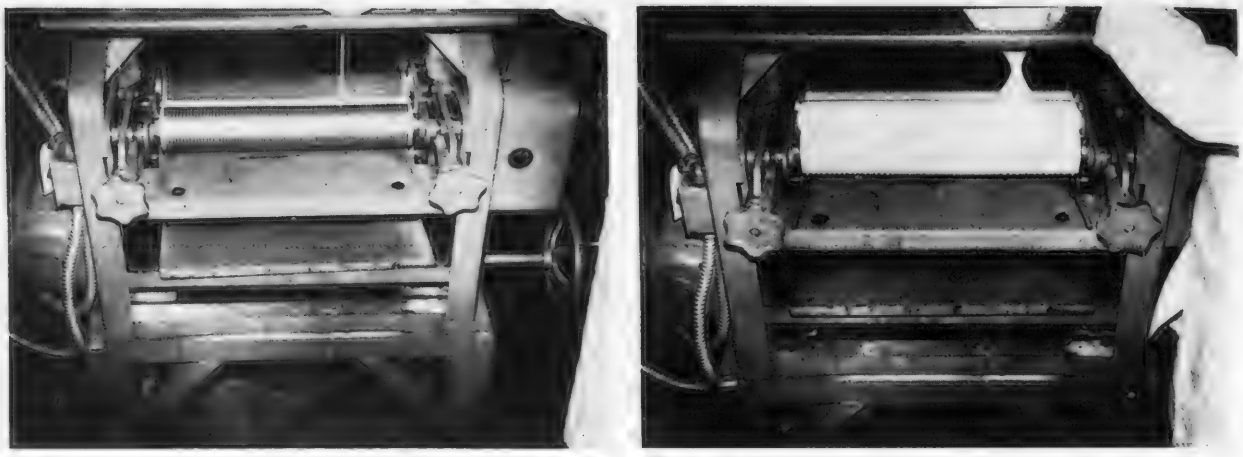


Unfoamed urea resin on the spreader.

flour of various types, clays, barks, and oat hulls are commonly used in various adhesives. In some cases, blood, starch and other proteins serve as extenders for synthetic resin adhesives, in addition to supplying bonding qualities of their own.

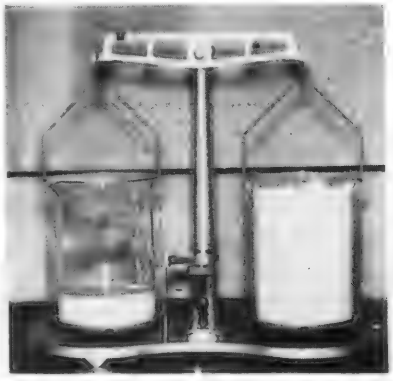
Air Decreases Penetration, Increases Bulk

Air, introduced into an adhesive in the form of a finely dispersed foam, has often been considered to have excellent possibilities as an extender. It is cheap and gives the adhesive two characteristics in particular that are often quite desirable in gluing: decreased penetration and increased bulk. A foamed adhesive has excellent resistance to penetration, and the resulting increase in bulk is desirable for spread coverage, particularly on rough surfaces. The idea of foaming an adhesive is not new, and attempts have been made both here and abroad to use foamed glue, but they have found limited, if any, commercial application. The chief problem has been in controlling and stabilizing the foam so that, after it has been foamed to a precise level, it will neither break down nor increase in volume while being applied by conventional means.

Arthur D. Little, Inc., working jointly with industry, has developed a technique of mechanical foaming that produces stabilizing foams that can be handled in commercial operations without excessive control and without major alteration of application equipment. The major accomplishment leading to the success of this system is the development of a line of foam-stabilizing agents. Specific forms of these agents are added to each particular adhesive mix. The foam-stabilizing materials, while relatively expensive, affect the final mixed glue cost only slightly because their usage, based on the total mixed glue, is small. Patents have been applied for covering this and other aspects of mechanical foaming. By means of this technique, stable foams have been produced with most types of adhesives in commercial use, including phenolic, urea, and melamine resins, urea-melamine combinations, soya, blood, starches, polyvinyl acetate emulsions, sodium silicate, animal glues, and various specialized adhesive formulations. In each case, the stable foam was produced by incorporating a foam-stabilizing agent in the mix and by making only minor formulation changes to adjust viscosity, pH, solids content, and in some cases modify or eliminate the filler.

A special foaming unit, located at or near the spreader, can be designed to produce from 200 to 800 pounds of glue per hour, which is sufficient for most spreading operations. In plywood operations a modified Hobart mixer has been used, but other equipment manufacturers are developing additional types of mixers, as well.

For maximum control, a separate foaming unit should be used for each spreader. This, in addition to better foam control, offers the most flexibilit for changing from one adhesive typ to another and for cleaning the equi ment. In plywood in particular, it also necessary to alter roll grooving t give adequate spread volume wit foamed adhesives that have specif gravities in the 0.20 to 0.40 range. F most applications, a spreader roll wit 10 grooves per inch and approximatel 0.036 inch deep works well wit foamed adhesives.



Comparison of unfoamed and foamed urea resin volumes.

How the Adhesive is Foamed

Foaming is continuous, with th rate of foaming adjusted to the ap proximate rate of adhesive use. Mechanically foamed adhesives have good stability, and will remain foamed for an hour or more, but they will not remained foamed for several hours or overnight; therefore, any glue that has to be held over should not be foamed. Continuous foaming just prior to use reduces wastage of what would otherwise be unused foamed glue that could not be held over for later use.

The procedure for foaming is as follows:

1. Adhesive is mixed in a conven tional glue mixer, with all ingredients being blended and the necessary foam stabilizing agent added.

2. Mixed adhesive is passed through the mechanical foaming unit at ap proximatly the rate it is being spread so that no large volume of foamed ad hesive is prepared ahead of use. Th glue is stored and handled unfoamed with the foaming unit located as clos to the spreader as possible.

3. Adhesive is foamed to 3 to times its original volume and pumpe to the spreader.

4. A conventional spreader is used with only the roll grooving modified so that a sufficient volume of the low specific-gravity foam can be applied.

Advantages of Foamed Adhesive

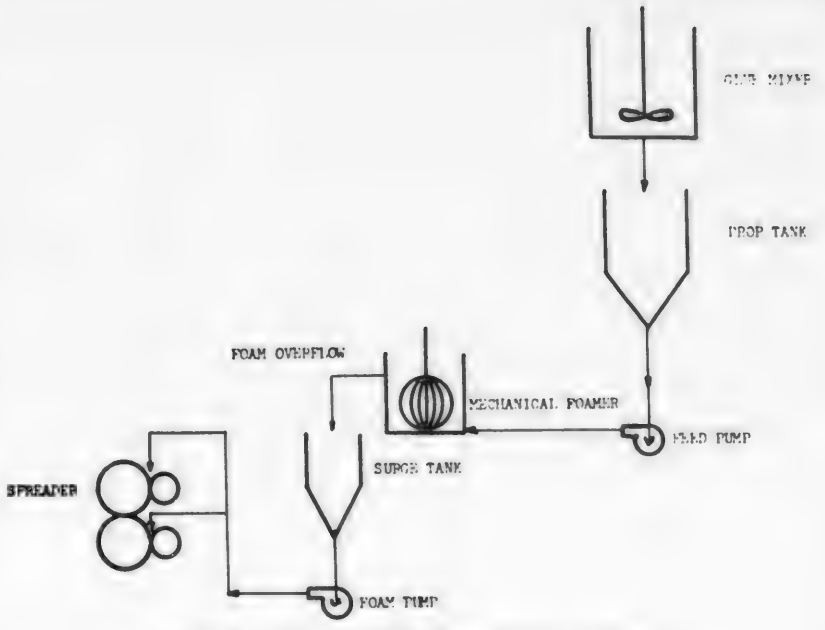
Foamed adhesives have several characteristics that have a marked influence on wood gluing. The increased volume of several fold gives better coverage, more uniform spread control, and the possibility of reduced glue usage without affecting bond quality. The physical nature of foam—its stiffness and even air dispersion—produces less penetration into the surfaces being glued, greater assembly time flexibility, and faster setting qualities. Reduced adhesive penetration further reduces glue requirements because of less need for a high margin of safety to make up for adhesive loss through penetration.

The use of foam-extended adhesives results in faster bond cure because 1) less glue is being used; 2) there is less water or solvent in the mix; or 3) high-cost, resin is incorporated in the mix without an increase in cost.

Foaming procedures can be applied to most adhesives used in wood gluing, so it follows that foamed adhesives can be used for most wood-gluing operations. Certain types of products and gluing procedures are more adapted for foam use than others; some operations, which use very small quantities of adhesives, cannot, justify the cost of installing foaming equipment, even though the glue saving possible is a sizeable percentage of the total usage. It is necessary to tailor the foaming technique to each specific gluing job, and the extra equipment that is necessary to foam adhesive mechanically, though not expensive, must be amortized out of savings.

Laboratory tests and field experience have shown that foamed adhesives have good application in both hardwood and softwood plywood. The increased adhesive volume that results with foaming gives good coverage on veneer core even at low spread weight levels and on rough, had-to-cover surfaces. In addition to lower glue usage because of lower spread, there is less wastage through reduction in the amount of discarded, poorly spread veneer. Other advantages in using foamed glue in plywood are slightly reduced press time, good assembly characteristics, and reduced penetration. Spread control is excellent because of even foam stability and viscosity control.

Foamed adhesives offer similar advantages in other glued wood products, such as, flush doors, timber laminates, edge-glued lumber, paper-coated veneer, and many other products. In the paper-coated veneer field, the characteristics of foamed glues that are important in plywood are even more advantageous, primarily because of the high absorptive characteristic of paper and the generally rough character of the veneer used. In this application, it has been possible to use higher-cost, more durable adhesives that can be applied at lower spread levels and still decrease glue-line costs by foaming.



Schematic layout of a typical adhesive foaming operation.

Laboratory work has indicated that foamed binders for particle board offer very interesting possibilities. The increased volume of binder provides better dispersion throughout the wood-particle mat. The blending of a relatively small amount of binder into a large volume of wood particles is a difficult problem; by foaming the binder, the volume can be increased as much as tenfold. In addition, the foamed binder has less tendency to penetrate into the open structure of the particles, and the foam, because of its physical form, blends well during mixing. As in all bonding operations, the foam breaks during pressing, and the foam structure is lost.

Many paper applications, such as solid fiberboard laminating and corrugated fiber laminating, can make use of foamed adhesive. For some paper gluing, in which the weight of glue required to give a satisfactory bond is so low that it is difficult to apply a film physically that is sufficiently thin, foaming increases the film thickness so that the adhesive is easier to apply.

The application of foamed adhesives certainly will not revolutionize the glued products field, but advantages that have been proven for some operations in the field and indicated for others in the laboratory will have a definite affect on the application of many types of adhesives. Air extension offers industry adhesives with characteristics that cannot be duplicated with other types of extension. Improvement of gluing operations through better coverage, easier spread control, and less waste will certainly prove important in improving product quality.

In addition, the properties of foamed adhesives may make it possible to bond extremely porous materials that in the past have been impractical to bond because of extremely high adhesive cost. Also, the lower glue-line cost that can be achieved will assist in improving marginal profit levels in many wood-gluing operations. Finally, application of foaming techniques will lead to expanded use of high-cost adhesives.

Each gluing operation has to be considered by itself from the two viewpoints of technology and economics. But with the basic foaming system worked out, there is little doubt that it will find wide application in even as yet unthought-of operations—albeit with modifications to suit specific requirements.

Air Drying 4/4 Red Oak

IN SOUTHERN WISCONSIN[1]

E. C. PECK

Forest Products Laboratory,[2] Forest Service, U. S. Department of Agriculture

Average drying time for 4/4 flooring stock was 117 days. Well air-dried lumber was not available from late October to early May. Roofing was worthwhile, but sloping and pitching were not.

Fig. 1.—Building a stickered package for a pile sloped and pitched lengthwise.

OAK FLOORING STOCK, like many other hardwood products, is commonly air seasoned to remove most of the moisture in it before it is kiln dried to final moisture content. This practice, of course, greatly reduces the length of time required for kiln drying the denser hardwoods, and drying costs are thereby lowered. Also, since such woods are relatively difficult to kiln dry as compared with, for example, the softwoods, preliminary air seasoning is preferred even though total drying time is greatly lengthened thereby.

Experiments in air drying were conducted during 1956 and 1957 on 4/4 red oak flooring stock at the Sawyer Tie Co., Sauk City, Wis. The objects were to determine the number of days required to bring lumber to a moisture content of 20 percent when piled at different seasons of the year, and the amount of drying defects that developed in yard piles of several types. The types included roofed and roofless piles, horizontal, and sloped and pitched piles. The position of the stickers was also varied with reference to the board ends at one end of the packages or piles to determine how much degrade was induced by this factor.

The lumber for the study was obtained from the green chain of the mill. The experimental material was principally No. 2 Common, with some No. 3A and some No. 1. The boards were of random width and 8 feet 6 inches long. The total amount of lumber required for each set of seven experimental piles was approximately 9,000 board feet.

Description of Experimental Piles

The lumber was built into stickered packages of 17 courses, about 3 feet high, 40 inches wide, and 8½ feet long (Fig. 1). Each pile consisted of three packages (Fig. 2). There were seven piles in a set, four roofed and three roofless. Five piles in each set were level or horizontal, and 2 were sloped and pitched, one lengthwise and one sidewise. The packages of the sloped and pitched piles were built with a pitch of 1 to 6, or twice that of slope of the pile, 1 to 12. The position of the tier of stickers at one end was varied in the four horizontal and roofed piles: projecting 1 inch, flush, and 6 inches and 18 inches from the board ends.

The seven experimental piles were placed in an inner row of the yard with at least one shield pile at each end. The piles were supported at the ends and middle on foundations made from ties laid flatwise. The distance from the ground to the bottoms of the piles varied, because of irregularities in the surface of the ground, from about 6 to 10 inches. The rows of piles in the yard were about 3 feet part, and the distance between the sides of the test piles in the row was 18 to 2 inches. The pile that sloped lengthwise was placed so that the high end faced west, and pitched so that the high or west end had an overhang (Fig. 3). The pile that sloped sidewise wa

[1] Presented at Session XI, Wood Drying (Applied) FPRS 12th National Meeting, June 22–27, 1958, Madison, Wis.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

The Author: Edward Peck holds MF and PhD degrees from the Yale School of Forestry. He joined the FPL in 1921, and has worked mainly on the bending and seasoning of wood.

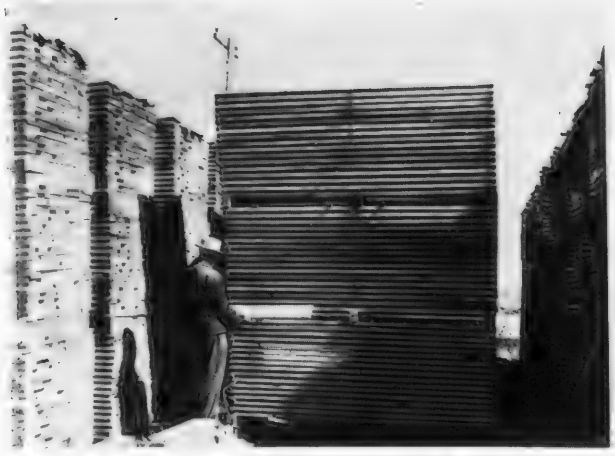


Fig. 2.—Experimental pile of 3 stickered packages. This pile is sloped and pitched sidewise. Position of pile samples is shown.

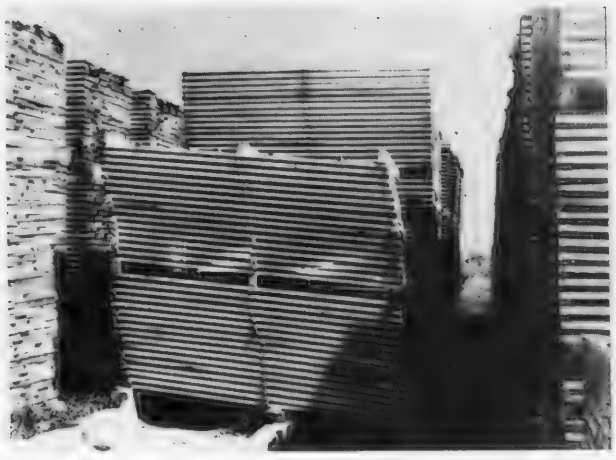


Fig. 3.—The bottom and middle packages of a pile that was sloped and pitched lengthwise.

placed so that the high side faced south, and pitched so that high or south side had an overhang.

The regular sawmill stickers were used in building the test packages. These air-dried, rough red oak stickers were a little over 1 inch thick and 1 inch to about 4 inches wide. Three tiers of stickers were used, one in the center and one at either end of the boards. The stickers were placed flush with the ends of the boards, except in three of the test piles, where the position of the end tiers of stickers at the west end was varied as mentioned above.

An effort was made to place the boards edge-to-edge in the courses. When this was impossible, the spaces between the edges of the boards that resulted were distributed so that they did not fall always near the same side of the package.

A total of 189 of the 8½-foot boards were selected from the green lumber of each set and designated "whole-board samples." Three whole-board samples were placed in the second, ninth, and sixteenth courses of each test package. In each course, one was placed near the center and the others at the edges.

Pile samples were prepared from boards selected from the green lumber of each set. Fifty-two of the pile sample boards were cut 42 inches long, and four of them were cut 18 inches long. The latter were used in the piles where the stickers were placed 18 inches from the board ends. The pile samples were end-coated to reduce end drying so that their drying would be comparable to that of the long boards. The pile samples were weighed and placed on stickers within the bolster spaces, four between the top and middle packages and four between the bottom and the middle packages of the (Fig. 2). The samples were placed near the center of the pile, away from the edges.

As mentioned, each set contained four roofed piles and three roofless. The roofed piles were horizontal and differed only with respect to the position of the sticker at or near the west end. The roof consisted of a sheet of asphalt-impregnated and duplexed kraft paper with reinforcement. The sheet was cut slightly larger than the top of the pile, and so projected several inches at the ends and sides of the pile. The sheet was held down by placing three boards on the top. One of the three roofless piles was level or horizontal, one was sloped and pitched lengthwise, and one was sloped and pitched sidewise.

A set of piles was placed in the yard during each season of the year, namely, during July and October of 1956 and January and May of 1957. The piles remained in the yard until the weights of the pile samples indicated that the lumber had reached a moisture content of about 20 percent. Subsequent to air drying, the lumber of the October piles was kiln dried to a moisture content of 6 to 7 percent.

The pile samples were periodically weighed during and at the end of the air-drying process. When the pile samples were cut from the boards, sections for the determination of moisture content by the oven method were cut adjacent to each end. With the oven-dry weight of the sample known, their moisture content at intervals during the drying process was readily computed. Additional moisture-content sections were cut from the middle of the pile samples at the end of the air drying, for the purpose of correcting or adjusting the original calculated oven-dry weight of the sample.

The whole-board samples were weighed again after they were air dried. Sections for the determination moisture content by the oven method were cut 18 inches from the east end of the whole-board samples at the termination of air drying. The green moisture content of each whole-board sample was computed from its original and calculated ovendry weights.

The lumber for the July and October piles and for one of the January piles was graded in the green condition. All boards in the test packages were graded after they were air dried. All boards of the October piles were also graded after kiln drying and dressing on both faces to a thickness of about 7/8 inch. Surface checks were measured on the pile samples during and after air drying and on the whole-board samples after air drying. End splits were measured in all of the boards, including the pile samples, in all piles, with one exception; in the roofless piles of the July set the end splits were measured in whole-board samples only. The amount of end splitting was recorded in terms of the total inches of length present and in terms of the longest end split present in the west end of the board.

The Data

Climatological: Sauk City is about 25 miles northwest of Madison, Wis. Weather records are not taken at Sauk City, so those taken at Truax Field, Madison, were used. The weather from the middle of April to the middle of October favors rapid air drying. Air drying takes place more slowly during the remainder of the year, and particularly from the latter part of November to about the middle of March, when the average temperature is below freezing.

From July through December 1956, both the temperature and the relative humidity averaged slightly above normal. From January through July of 1957, the temperature averaged about

normal and the relative humidity slightly below normal. From July through December of 1956 the precipitation averaged normal. In May and June of 1957, the precipitation was appreciably above normal.

The equilibrium-moisture-content values for wood, corresponding to the mean temperatures and relative humidities of the various months, ranged from about 12½ percent during May, June, and July to 14 and 15 percent in November to March. These values indicate that lumber piled in the yard for air drying can reach a moisture content of 20 percent during any month of the year. During the winter months, however, the diffusion of moisture is so slow that the average moisture content of lumber remains considerably above 20 percent, although the moisture content of the surfaces may be below this figure.

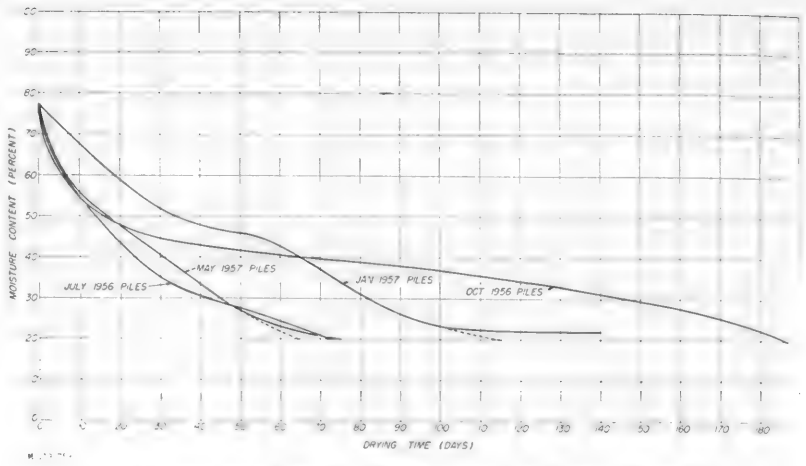


Fig. 4.—Air-drying curves for red oak flooring stock, based on average moisture content of pile samples.

Drying: *July 1956 piles.*—These piles were erected from July 25 to August 2. The lumber was dried to a moisture content of 20 percent in about 72 days (Fig. 4), Near the middle of the drying period there was an abrupt retardation of drying. This was presumably caused by the excessive rain that fell at and immediately preceding this time. The relative humidity was higher and the rainfall was greater than normal during August. During September and October, the last half of the drying period, both the relative humidity and the rainfall were below normal.

October 1956 piles.—The lumber in the piles erected from October 19 to 25 dried slowly from the latter part of November until about the first of March because of the below-freezing temperatures.

January 1957 piles.—Threse piles were erected from January 22 to February 4 during the inactive drying period of the year, and were taken down during June. The frozen lumber piled during this period lost an appreciable amount of moisture from the surfaces of the boards over the first 30 days. During the next 30 days the drying was slow. Actually, the lumber did not reach a moisture content of 20 percent, although it stood in the yard for 140 days. The relative humidity and precipitation during the months of May and June 1957 were considerably above normal. As a result, the lumber that had reached a moisture content of about 22 percent after air drying for 110 days lost practically none during the next 30 days. Had this exceptionally damp spell not occurred, the drying period possibly would have been about 115 days, as is indicated by extrapolating the slope of the drying curve at about the 98th day (Fig. 4). During the latter part of March, the outdoor temperatures averaged about 32° F. and the thawed lumber began to air dry at an accelerated rate.

May 1957 piles.—These piles were erected from May 7 to 24. The pile samples actually reached a moisture content of 20 percent after 75 days. During the months of June and July the precipitation was greater and the relative humidity higher than normal. It was estimated by extrapolating the drying curve (Fig. 4) from the trend at the 50th day that under normal conditions the lumber would have reached a moisture content of 20 percent in 65 days.

Comparison of piles.—Fig. 4 shows that the lumber in the July, October, and May piles dried at about the same rate for the first 10 days. The drying rate of the October piles declined appreciably after about the 20th day when the weather became cool and moist. From the 10th day onward the lumber in the July piles dried more rapidly than that in the May piles because of the abnormally wet weather during May of 1957. After the 30th day, the drying of the lumber in the July piles began to slacken, and after 48 days the moisture content of the lumber in the May and July piles was approximately the same. The October piles remained in the yard all winter, and the drying during this period was extremely slow. The lumber piled in January dried slowly from the very start because of the frozen state of the lumber and the low temperatures and high relative humidities during the months of January, February, and March. After 65 days of air drying, the moisture content of the lumber in the January and October piles was down to 40 percent. After this number of days, the lumber in the January piles dried at a considerably faster rate than that in the October piles, because at about this time the January piles entered the season of the year that is included in the active drying period and because, further, after the same number of days the October piles became subject to winter conditions that correspond to the period of the year during which drying is retarded.

That the use of pile samples for tracing the drying rate in the piles themselves is a satisfactory procedure is shown by the moisture content data collected on the 189 whole-board samples. The average green moisture content of the whole-board samples was 0.2 percent lower than the average green moisture content of the pile samples. The average final air-dry moisture content of the whole-board samples was 0.5 percent above that of the pile samples.

The relative loss of moisture of the four sets during the first 60 days is shown in Fig. 5. Expression of the loss in percent of the evaporable moisture makes allowance for differences in the average green moisture-content values of the lumber. The lumber of the July, October, and May piles lost about the same relative amount of moisture during the first 10 days. The relative rate of moisture lost by the lumber in the May piles was severely retarded from the 10th to the 20th day, during which there were five rainstorms, but after the 20th day the drying of this lumber proceeded at about the normal pace. There are considerable differences in the characteristics of the drying of the lumber in the October and the January piles up to 50 days, but after that time they have about the same rate of moisture loss. These curves show that 50 percent of the total drying of the lumber in the July, October, and May piles occurred in about 20 days, and in the January piles in about 45 days. These dat

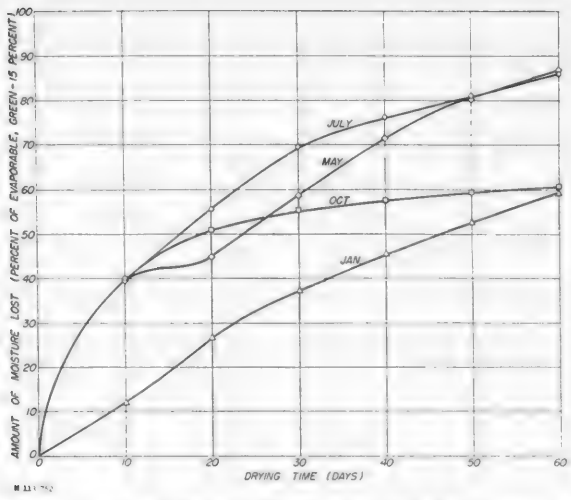


Fig. 5.—Curves showing the relative amount of moisture lost for the 4 sets of piles plotted against time.

might be used to establish a time schedule for a seasoning process consisting of air drying followed by kiln drying. For exampde, the following air-drying schedule would deliver 4/4 red oak lumber to the dry kilns at a moisture content of approximately 30 to 40 percent: Lumber piled from the months of September to December, inclusive, 90 days; January to March, inclusive, 60 days; and from April to August, inclusive, 20 to 30 days.

When the piles were dismantled, the average moisture content of the whole-board samples in the bottom packages was higher than that of those in the top packages in 25 of the 28 piles. The moisture content of the samples in the middle packages was intermediate, except for seven piles, where it was lower than that of the top packages. These exceptions were presumably caused by absorption of rainwater by the samples in the top packages shortly before the piles were dismantled. Considering all piles, the average moisture-content values of the whole-board samples at the end of the drying period were: in top packages 19.4 percent, middle packages 20.1 percent, and bottom packages 22.3 percent. For the roofed piles only, the averages were: top packages 18.7 percent, middle packages 19.6 percent, and bottom packages 22.1 percent. For the roofless piles the average values were: top packages 20.2 percent, middle packages 20.7 percent, and bottom packages 22.6 percent.

The moisture-content data indicate that the conditions near the ground are less favorable to drying than those 8 to 11 feet above the ground. This means that the air in the yard is not circulating freely at the ground level and several feet above it. The low and continuous bulk-head type of pile foundations, the weedy condition of the ground, and the closeness of the piles in the rows are responsible for the cool, moist conditions surrounding the bottom packages of the piles.

At the time of dismantling, the average moisture content of the whole-board samples in the roofed piles was 20.1 percent, while that of the samples in the roofless piles was 21.2 percent. The greatest difference was between the moisture content of the whole-board samples of the top packages. The lack of protection and the consequent intermittent wetting were responsible for the retarded drying and the resulting higher final moisture content. In the roofless piles, the average moisture content of the whole-board samples of the sloped and pitched piles was 20.9 percent, while the figure for the horizontal piles was 21.9 percent. The difference between these values is statistically significant at the 5 percent point, and may indicate that the boards in sloped and pitched piles dry somewhat faster than those in horizontal piles.

Air-drying periods for 4/4 red oak. —Fig. 6 is a chart that shows the number of days required to dry green 4/4 red oak to a moisture content of 20 percent when piled during every month of the year. The solid bars on the chart represent the number of days required to reduce the moisture content of the lumber in the test piles to 20 percent. The hollow bars are interpolated. The time required to air dry 4/4 red oak lumber to a moisture content of 20 percent varies from 65 to 212 days. The minimum drying period would be required for lumber piled near the middle of May, while the maximum drying period would be required for lumber piled during September. There probably are no practical differences between the drying periods required for lumber piled during the months of May, June, and July, and they can be considered to be from 60 to 70 days. These shorter air-drying periods all lie within the active drying period of the year. The average of the periods shown on the chart is 117 days. If lumber is piled each month and held in the yard until it reaches a moisture content of 20 percent, the greatest accumulation will occur during the month of May. At this time the yard will hold 6 to 7 months' production accumulated since November of the preceding year.

Surface Checking: Table 1 gives the occurrence of surface checking in terms of total inches of length on both faces for the pile and the whole-board samples. Since the pile samples were generally 42 inches long, with some 18 inches long, the inches of surface checks were adjusted to correspond to the 8½-foot length of the whole-board samples. Surface checking in the pile samples was greatest in the piles erected during May, and least in the piles erected during October. The whole-board samples of the October piles surface-checked the most, while those of the July piles surface-checked

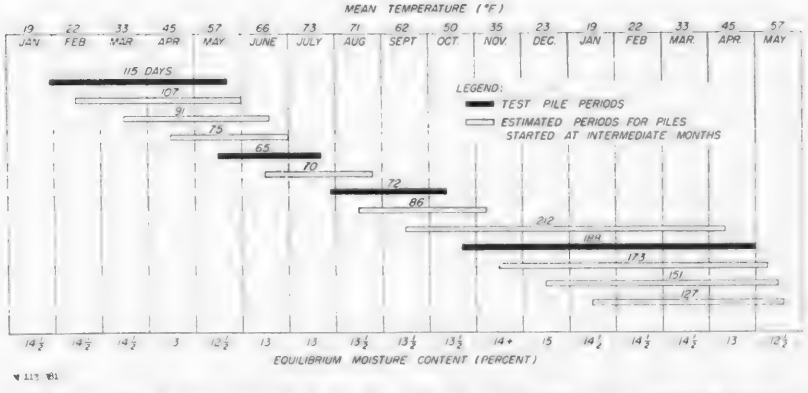


Fig. 6.—The periods required to air dry 4/4 red oak Common to a moisture content of 20 percent for piles erected during each month of the year.

the least. The average amount of surface checks in the pile and whole-board samples combined was 29.1 inches in the roofless piles and 21.8 inches in the roofed piles.

The pile samples would be expected to surface check less than the whole-board samples because all were in more sheltered positions; a considerable number of the whole-board samples were on the edges of the piles. However, the average total inches of surface checks in the pile samples was 40.9, and in the whole-board samples it was 20.2. The method of inspection for surface checks is the only explanation for this appreciable difference and unexpected order. The pile samples were examined at frequent intervals during the air-drying process, while the whole-board samples were examined only at the end. Since the surface checks closed during the latter part of the drying process, some of the surface checks in the whole-board samples may have been invisible in the final air-dry condition.

A statistical analysis of the surface checking data, for the whole-board samples only, shows that the surface checking in the October piles was significantly greater than that of all of the other piles, and the surface checking in the January piles was significantly greater than that in the May and July piles. Surface checking was greater in the roofless than in the roofed piles. The whole-board samples in the top packages surface-checked significantly more than those in the bottom and middle packages. The whole-board samples on the edges of the piles surface-checked more severely than those in the center. A separate analysis of the surface checking data for the three roofless piles, horizontal, sloped and pitched lengthwise, and sloped and pitched sidewise, indicated no significant difference in the amount of surface checking attributable to slope of boards and pitch of pile.

End Splitting: Table 2 gives the amount of end splitting in the west ends of all boards except the pile samples. The values in the table are averaged total number of inches of end splits present per board, and the average length of the longest end split present in each board. The end splits were measured on both faces of the board. On the basis of the total inches of end splits, the average for the January set of piles is greater than that for July, October, and May. The end splits were longer in the boards of the July piles than in the January, October, and May piles. Roofing the piles reduced end splitting. End splitting was significantly greater in the top portions of the piles than in the lower parts. Sloping and pitching the piles had no effect on the length of the longest end split. The total amount of end splitting in the whole-board samples of the piles that were sloped and pitched lengthwise was significantly less than that in the piles that were horizontal, or in the piles that were sloped and pitched sidewise. The overhang of the west end of the pile that was sloped and pitched lengthwise would protect the ends from wetting.

A statistical analysis of the data for total end splits in those piles where the position of the stickers was varied showed that the projecting stickers caused a significant reduction in comparison with the other three positions. The stickers that were placed 18 inches from the board ends caused a significant reduction in the total amount of end splits when compared with the flush stickers and the stickers that were 6 inches from the board ends. The projecting and the flush stickers caused a significant reduction in the length of the longest split, compared to the 6-inch and the 18-inch positions. Where the stickers were 6 inches from the board ends, the longest end splits were significantly longer than those for the three other positions.

Degrade: Table 3 gives the losses in value in terms of dollars per thousand board feet and in percentage of green value. The average loss in value of pieces degraded in air drying for all piles amounted to $0.73 per thousand board feet of the original green lumber, or 0.81 percent of the green value. The significant revelation of this table is the relatively slight overall cost represented by the value of degraded pieces. The principal reason for the low loss was the grade of the lumber. The lumber averaged slightly above No. 2 Common, and the majority of the defects developing during the air drying, namely surface checking and end splitting, were permitted under the grading rules.

The average loss per thousand board feet in the roofless piles was $0.99, while in the roofed piles it was $0.54. From a statistical standpoint, the difference between them is highly significant. The average loss in value of the lumber in the January piles was the greatest, $1.01 per thousand board-feet, while that for the lumber of the July piles was the least, $0.52. The loss for the January piles was significantly greater than the losses for the July and October piles.

The average loss per thousand board feet for the boards in the bottom packages of the roofed piles was $0.28, for the middle packages $0.59, and for the top packages $0.75. The difference between the loss for the top and bottom packages is highly significant. The corresponding values for the roofless piles were $0.17, $0.40. and $2.39. The differences between the loss for the top packages and the losses for the bottom and middle packages are highly significant.

Of the three roofless piles, the average losses in those that were sloped and pitched were greater than those in the horizontal piles, but the difference were not significant.

Degrade in the Boards of the Top Courses: Boards in the top course of the piles that were not roofed usually dropped in grade and in value through checking, splitting, and warping. If Select grades had been used in the experiment, the losses would undoubtedly have been greater. Table 4 gives the losses in value of the boards in the top course of each pile. The figures given under the colum "Per pile" were obtained by adding the losses for the boards in the top course. The figures in the other column express the total losses in terms of percent of the green values of the boards of the top course.

For the roofless piles, the boards of the top course lost an average of $0.73 per pile, while for the roofed piles the average loss was $0.06. The pile roof therefore saved an average of $0.72 a pile. The roofing material, which was composed of two sheets of kraft paper, asphalt-coated and impregnated, cost approximately $0.01 per square foot. The cost of a roof would therefore be about $0.36 per pile. If the roof was in good condition when the pile was dismantled, it was saved and used again. Assuming an average use of twice, the cost of the roofing material per pile would be $0.18. Since it required only a minute or two to cut the roofing material, lay it on the top of the pile, and lay three old boards on it to hold it in place, no labor charge was made against the roofing operation. On this basis, the net saving per pile was $0.54.

The saving resulting from roofing the pile may be calculated by another method. The average loss in value for all the lumber of the roofless piles was $0.99 per thousand board feet, while for the roofed piles it was $0.54. The difference, or $0.45, adjusted according to the approximate board-feet in a pile, 1,200, equals $0.54. If the cost of the roof is taken as $0.18, the net saving per pile is $0.36.

Degrade After Kiln Drying and Planing: Table 5 gives the losses in value of the lumber of the October set of piles graded in the rough air dry state, and in the dressed kiln-dry state. The lumber of all piles but one showed additional degrade and loss

Table 1.—SURFACE CHECKING DURING THE AIR DRYING OF 4/4 RED OAK AT SAUK CITY, WIS., PILED IN JULY AND OCTOBER 1956, AND JANUARY AND MAY 1957[1]

Type of pile	Surface checks								
	July		October		January		May		
	Pile samples In.	Whole-board samples In.	Pile samples In.	Whole-board samples In.	Pile samples In.	Whole-board samples In.	Pile samples In.	Whole-board samples In.	Weighted average In.
Horizontal, roofed; stickers flush	20.2	4.0	17.1	30.4	84.6	4.9	65.8	7.3	19.7
Horizontal, roofed; stickers projecting 1 inch	30.4	2.2	7.9	54.2	56.0	7.8	34.8	8.3	21.3
Horizontal, roofed; stickers 6 inches from end	30.0	3.3	3.9	33.8	24.9	10.9	44.0	40.9	23.0
Horizontal, roofed; stickers 18 inches from end	41.4	5.1	28.1	44.3	14.0	8.7	111.6	2.9	22.9
Horizontal, roofless; stickers flush	27.6	7.1	9.1	31.2	31.6	35.2	55.1	16.6	24.4
Sloped and pitched lengthwise, roofless; stickers flush	51.1	38.8	97.0	21.8	46.0	18.9	49.4	5.7	30.3
Sloped and pitched sidewise, roofless; stickers flush	57.1	11.6	17.2	59.1	48.1	46.6	40.5	3.2	32.5
Average	36.8	10.3	25.8	39.3	43.6	19.0	57.3	12.1	----
Weighted average[1]	16.4		36.2		24.7		22.4		----

[1]Total inches in length in a board length of 17 feet (namely, equivalent to both faces of a board 8½ feet long).
[2]The surface checking values for the shorter pile samples were adjusted to correspond to the 8½-foot whole-board samples.
[3]Weighted average of 32 pile samples and 108 whole-board samples.
[4]Weighted average of 56 pile samples and 189 whole-board samples.

Table 2.—TOTAL LENGTH OF END SPLITS PER BOARD AND LENGTH OF LONGEST END SPLIT IN THE WEST END OF BOARDS[1]

Type of pile	End splits									
	July		October		January		May		Average	
	Total In.	Longest In.	Total In.	Longest In.	Total In.	Longest In.	Total In.	Longest In.	Total In.	Longest In.
Horizontal, roofed; stickers flush	9.2	1.6	9.0	1.4	8.8	1.2	9.1	1.2	9.0	1.3
Horizontal, roofed; stickers projecting 1 inch	6.6	1.5	7.4	1.4	6.1	1.0	4.6	1.2	6.2	1.3
Horizontal, roofed; stickers 6 inches from board ends	9.5	2.1	9.1	1.2	7.5	1.7	11.1	2.1	9.3	1.8
Horizontal, roofed; stickers 18 inches from board ends	6.6	1.7	8.6	1.3	9.9	1.4	6.9	1.4	8.0	1.5
Horizontal, roofless; stickers flush	13.0[2]	2.3[2]	9.9	1.1	14.1	1.4	11.1	1.2	11.8[3]	1.3[3]
Sloped and pitched lengthwise, roofless, stickers flush	17.3[2]	2.5[2]	7.4	1.4	12.0	1.5	4.8	1.0	8.4[3]	1.3[3]
Sloped and pitched sidewise, roofless, stickers flush	15.8[2]	2.6[2]	6.6	1.2	17.3	1.5	9.4	1.1	11.3[3]	1.3[3]
Average	8.4[3]	1.8[3]	8.3	1.3	10.8	1.4	8.2	1.3	9.0[3]	1.4[3]

[1]Includes all boards in the pile (except as otherwise noted) but not including pile samples.
[2]Values apply to whole-board samples only.
[3]Weighted average.

Table 3.—LOSS IN VALUE CAUSED BY DEFECTS DURING THE AIR DRYING OF 4/4 RED OAK AT SAUK CITY, WIS.[1]

Type of pile	Loss in value									
	July		October		January		May		Average	
	Per M.b.m. Dollars	Ratio of green value Percent	Per M.b.m. Dollars	Ratio of green value Percent	Per M.b.m. Dollars	Ratio of green value Percent	Per M.b.m. Dollars	Ratio of green value Percent	Per M.b.m. Dollars	Ratio of green value Percent
Horizontal, roofed; stickers flush	0.58	0.61	0.13	0.16	1.51	1.67	0.15	0.18	0.60	0.68
Horizontal, roofed; stickers projecting 1 inch	.19	.21	.91	1.17	.93	1.07	.22	.25	.56	.63
Horizontal, roofed; stickers 6 inches from end	.18	.18	1.21	1.54	.55	.66	.39	.43	.58	.64
Horizontal, roofed; stickers 18 inches from end	.73	.73	.13	.17	.69	.81	.12	.13	.41	.45
Horizontal, roofless; stickers flush	.76	.82	.64	.81	.79	.91	1.03	1.11	.81	.90
Sloped and pitched lengthwise, roofless; stickers flush	.66	.70	.80	1.01	1.64	2.00	1.17	1.23	1.06	1.18
Sloped and pitched sidewise, roofless; stickers flush	.59	.65	.73	.92	.97	1.11	2.11	2.36	1.09	1.22
Average	.52	.56	.66	.74	1.01	1.17	.74	.82	.73	.81

[1]The following lumber prices were used to compute the losses in value: F & S $150, S $130, 1C $114, 2C $82, 3A $63, and 3B $45 per M.b.m.

Table 4.—LOSS IN VALUE CAUSED BY DEFECTS DURING THE AIR DRYING OF 4/4 RED OAK OF THE BOARDS IN THE TOP COURSE OF THE PILES

Type of pile	Loss in value									
	July		October		January		May		Average	
	Per pile[1] Dollars	Ratio of green value[2] Percent	Per pile Dollars	Ratio of green value Percent	Per pile Dollars	Ratio of green value Percent	Per pile Dollars	Ratio of green value Percent	Per pile Dollars	Ratio of green value Percent
Horizontal, roofed; stickers flush	0.00	0.0	0.08	3.6	0.00	0.0	0.00	0.0	0.02	0.9
Horizontal, roofed; stickers projecting 1 inch	.00	.0	.00	.0	.07	3.7	.00	.0	.02	.7
Horizontal, roofed; stickers 6 inches from end	.00	.0	.11[3]	3.9	.11	5.5	.00	.0	.06	2.3
Horizontal, roofed; stickers 18 inches from end	.00	.0	.25	11.3	.39	18.8	.00	.0	.16	7.3
Horizontal, roofless; stickers flush	.83	34.4	.82	35.5	.21	13.0	.93	40.4	.70	32.2
Sloped and pitched lengthwise, stickers flush	.77	35.0	.70	29.9	.87	36.9	.89	37.6	.81	34.8
Sloped and pitched sidewise, stickers flush	.56	23.9	.73	31.5	.75	33.0	1.34	46.7	.84	34.5
Average	.31	13.5	.38	16.2	.34	15.3	.45	17.9	...	...

[1]Total of losses in boards in top course.
[2]Based on graded value of boards when green.
[3]The loss of $1.06 was not used since the roof of this pile was blown off during the winter. The value shown was computed and is equal to the average loss for the other three roofed piles of the October set.

Table 5.—LOSS IN VALUE CAUSED BY DEFECTS DURING AIR DRYING OF 4/4 RED OAK AT SAUK CITY, WIS., FOR THE PILES ERECTED DURING OCTOBER 1956, GRADED ROUGH AIR DRY AND DRESSED KILN DRY

Type of pile	Loss in value			
	Rough air dry		Dressed kiln dry	
	Per M.b.m. Dollars	Ratio of green value Percent	Per M.b.m. Dollars	Ratio of green value Percent
Horizontal, roofed; stickers flush	0.13	0.16	1.21	1.49
Horizontal, roofed; stickers projecting 1 inch	.91	1.17	1.65	2.12
Horizontal, roofed; stickers 6 inches from end	1.21	1.54	1.45	1.84
Horizontal, roofed; stickers 18 inches from end	.13	.17	.44	.58
Horizontal, roofless; stickers flush	.64	.81	1.33	1.68
Sloped and pitched lengthwise, roofless; stickers flush	.80	1.01	.80	1.01
Sloped and pitched sidewise, roofless; stickers flush	.73	.92	1.69	2.13
Average	.66	.74[1]	1.22	1.55[1]

[1]Approximate values (average of the percentages).

when inspected after kiln drying and dressing. The causes for the increase in degrade were surface checks and splits and, in one instance, stain. The surface checks that were detected in the dressed boards were presumably invisible in the rough air-dry condition. The splits developed during planing, but since they were associated with cupping that developed during air drying, the degrade was charged against the drying process. The average increase in loss after kiln drying and planing was equal to 85 percent of the loss after air drying. If it is permissible to apply this figure to the average loss of $0.73 resulting from the rough air-dry inspection for the lumber of all piles, then the average loss per thousand board feet becomes $1.35, or 1.4 percent of the green value.

Conclusions and Recommendations

The time required to dry 4/4 Common northern red oak lumber to 20 percent moisture content varied from 65 to 212 days. Lumber placed on the yard in May, June, and July will require less drying time than any other period of the year. Lumber placed on the yard in September or later will not be dry until the following April or May. Well air-dried lumber is not available for shipment from the latter part of October to early May.

The average loss in value per thousand board feet was $0.73. This loss in value of the No. 2 Common boards used in the study was caused principally by degrade in those boards in the top courses of the roofless piles. A saving of $0.54 per thousand board feet was gained by roofing the piles with reinforced waterproof paper. Since the paper cover costs approximately $0.36, the net saving is $0.27 per thousand board feet. Since covers are reused, it appears definitely economic to roof the piles and this is recommended.

The least amount of end splitting was obtained when the tier of stickers at the end of the pile projected beyond the board ends. When the stickers were placed 6 inches in from the end, the worst splitting occurred. It is recommended that the stickers in these tiers be placed with the edges flush with the ends of the boards and, if practical, projecting beyond the board ends.

Sloping and pitching of the roofless piles had no important effect on surface checking, end splitting, or loss in value. The piling of lumber into packages with pitch, the construction of special pile foundations, and the lift-truck fork accessories increase overall yarding costs. Horizontal placement of packages is recommended.

Discussion

E. M. Conway (Lumber Drying Specialty Co.): I was astonished at the very low loss in value resulting from air drying this 4/4 oak. Would you care to comment on why the percentage loss in value was so low compared to that found in your 4/4 sugar maple air drying study made in the Upper Peninsula of Michigan?

Mr. Peck: Much of the difference is probably because most of the checking of the oak was not charged against the grade.

Mr. Conway: The checks were taken into account in the maple study?

Mr. Peck: There are differences in grading between the two species. The checking of the maple cause more degrade. Checking was examined after the maple was skip dressed. The defects were measured rather than depending entirely on grade.

R. M. Carter (N. C. State College): Can you explain why less checking occurred in the May and July months than in the January and October months? Your results show drying degrade to be greated in the winter months, which in contrary to general observations.

Mr. Peck: I found the same thing in studying the air drying of pine in Arizona and in studying air drying of beech in Philadelphia. This might conceivably be due to the slow moisture movement in frozen wood resulting in a thin surface zone in which drying stresses are concentrated and in which checking occurs.

Lawrence Leney (U. of Missouri): Do you believe the degrade due to checks in the upper part of the piles is the result of rewetting followed by drying, rather than the original drying? Would this explain the greater amount of checking and splitting during the winter months?

Mr. Peck: Yes, there would be a definite relationship between such rewetting and such drying defects as checking, warping, and stain.

S. B. Preston (U. of Michigan): To what do you attribute the greater splitting when stickers are 6 inches from the ends of the boards rather than 18 inches from the ends?

Mr. Peck: This is too complicated to discuss. There are a great many complicating factors, such as sheltering by the surrounding boards, differences in stress arising from differences in the restraint offered by the stickers, and so forth.

Theodore Ritsche (The Woodcraft Co.): Was the lumber used in this study cut at the time of year it was piled? Is better lumber obtained by cutting in the wintertime?

Mr. Peck: Yes, the lumber was selected from the green chain right after it was sawed. Winter-cut lumber would not be any better than that cut at any other time, except for staining, which would be reduced by low winter temperatures. The difference is primarily in the weather during drying rather than in the lumber.

Dry Process Hardboard[1]

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The development of various dry processes is discussed, with emphasis on differences between wet and dry processes and effect of these differences on board properties and equipment and operating techniques.

DRY PROCESS HARDBOARD is considered to be any hardboard produced by a process in which mat formation is done with air as a fiber conveying and distributing medium. The word dry should not refer to the condition of the fiber, but to the fiber conveying medium.

It has certainly been known for some time that wood fiber with low moisture content could be formed into hardboard. The only water actually needed at the time of pressing is that small amount required as a plasticizer. These known facts must have led a number of persons working in wood fiber research to give thought to the dry forming of a fiber mat for pressing into a sheet of hardboard. Added impetus was given to their work by the effluent problem confronting the pulp industry, as well as by the need for waste-wood utilization processes in areas without adequate water supply. Coupled with the knowledge that a hardboard, theoretically, could be produced from dry fiber, these were enough to set in motion and sustain the difficult job of development work in dry forming and pressing hardboard.

Commercial Installations

The first commercial installation of a dry process for hardboard manufacture was at the Anacortes Veneer plant in Anacortes, Wash. This plant utilized a process developed by the Plywood Research Foundation. In 1950 at the National Meeting of Forest Products Research Society, Harold Evans presented a paper that gave the details of the then-new process.

The second installation was made at Coos Bay Lumber in Coos Bay, Ore. The process was similar to the one at the Anacortes mill, but fiber was dried to lower moisture content, which eliminated the need for a screen during pressing and, thereby, permitted production of S2S board directly from the fiber mat.

The third plant, and last major installation to be made in this country, was consrtucted by the Weyerhaeuser Timber Co. at Klamath Falls, Ore. The process had been worked out by Weyerhaeuser's development group. At this plant is the first installation of a vacuum-type dry felter for hardboard. It is also the only process to use dry fiber classification and secondary refining of the coarse material. These are both major steps forward in the development of dry processes. Since the installation at Klamath Falls, several dry process hardboard plants have been constructed in foreign countries.

Differences Between the Wet and Dry Processes

The major differences between the wet and dry hardboard processes lie in the area between primary fiberizing and completion of pressing. This paper will be confined to a discussion of the processes between these points.

Most of the water used in a wet process serves as a conveying medium for the fibers. In the dry processes, air is substituted for water as the conveying medium. Major differences between wet and dry process equipment and operating techniques stem from the great difference in the characteristics of the conveying medium—one a liquid, the other a gas.

Fiber Drying: Within the last few years, the particle board industry, which uses direct drying, seems to have pointed the way to the best method for drying wood fiber. Flash drying of wood fiber suspended in air at high temperature by means of the products of combustion is, generally, the most economical method. An exception to this generalization would occur in small-output plants in locations where steam is available at very low cost. Under these conditions, it is quite practical to dry while the fiber is conveyed with air heated to less than 300° F. Recent installations of direct drying equipment to flash-dry pulp have provided all the basic information needed to apply the flash drying technique to the drying of fiber for hardboard.

Screening: Screening of stock or fiber for further refining of rejects is done in some, but not all, processes, both wet and dry. The end results are identical, but there is little similarity in the methods used to attain these results. Screening in wet-process plants usually follows one of the established methods used in the pulp and paper industry. To classify dry fibers in air requires the use of equipment adapted from other industries.

The basic piece of equipment now used is a mechanical air separator of the type normally used in conjunction with a pulverizer in the grinding and classifying of powerful materials. Rather extensive modification of the equipment is required. When it is properly adjusted, however, almost any desired degree of fiber classification can be obtained. Most companies that produce mechanical air separators have had little experience with its use on wood fibers. It is generally necesary, therefore, to do considerable pilot-plant work to establish the capacity and desired fiber classification of the equipment when used on the various wood species, at various moisture contents, and with various degrees of primary fiberization.

Refining: The secondary refining of coarse fiber is done in only one of the existing dry processes. The refiner used is a double-disc Bauer refiner. Material is fed by gravity with as much air sweeping of the refiner as is possible. The capacity of existing equipment used in this manner is relatively low, because the inlet to the refiner is not designed for material of low bulk density. The problems with this operation typify those often experienced in attempting to adapt wet process equipment to a dry process.

Other dry processes make no attempt to further refine the fiber after it is fiberized. The initial grinders are

[1] Presented at Session X, Wood Composition Board (2), FPRS 12th National Meeting, June 26–27, 1958, Madison, Wis.

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set to produce acceptable fiber. This is apt to increase the quantity of fine fiber above that necessary or even desirable. The present trend is to separate the fine fiber from the furnish and add it as a fines layer to the top of the fiber mat to improve the appearance of the board.

Fiber Metering and Felting: As complex as accurate stock metering may be in the head box of a fourdrinier machine, it is made less so by years of paper mill experience. To produce a competitive product, equally as accurate metering of dry fiber must be done in a dry process.

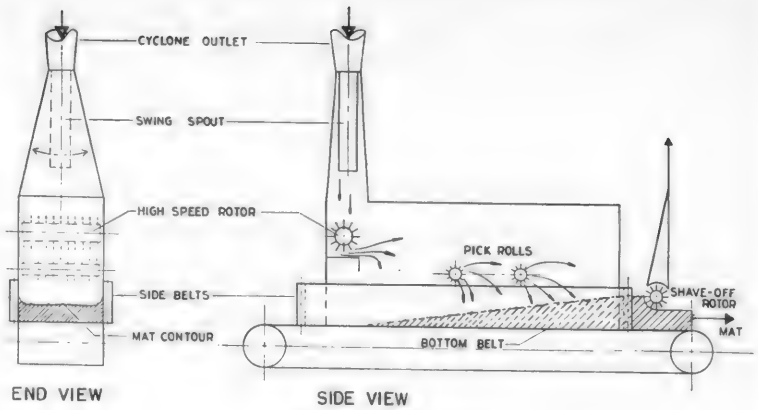
Metering in existing dry processes is done by control of fiber volume, and thereby requires uniform bulk density. Fiber moisture content, atmospheric conditions, air velocities, and fiber grind all influence bulk density, so all must be regulated and controlled. In present processes, metering of fiber is done either as an independent step prior to forming of the mat or after felting.

When metering is done prior to felting, a separate piece of equipment is used. It is generally labeled a volumetric feeder. In this machine, fiber is deposited in a bin at as near uniform bulk density as is possible. The bin serves to even out the surges from the previous system. Fiber is then fed from the bin at as near uniform rate as is possible, but at a rate of 25 percent greater than is required for felting. The fiber is fluffed and deposited as uniformly as possible on a belt with side deckles. A scalping roll, adjustable in height, removes the excess fiber and leaves a uniform volume of fiber for delivery to the felter. The excess fiber is recirculated.

There are two types of dry process felters in use today. In the snowfall-type felter, fiber is idscharged from a cyclone to a high-speed rotor located at the top of the felting box. Figuratively, a snowstorm of fiber is created within the box, and fiber gently settles out on the moving belt at the bottom of the box. The mat, 4 to 12 inches thick, passes beneath a fiber shave-off, which reduces the mat to uniform height as required for the thickness of board desired.

It must now be apparent that the volumetric feeder previously mentioned is a crude snowfall-type felter, and that the felter is a volumetric metering device. Hardboard plants that use the snowfall-type fleter do not meter fiber ahead of the felter, but meter the chip feed to the fiber-making equipment.

The second type of dry process felter is referred to as a vacuum felter. In this type of felter, the approach to the problem of obtaining uniform distribution of fiber is quite different from the snowfall or gravity felter. The premise on which the vacuum felter is based is that, once the fiber is uniformly distributed in air, it can be most uniformly felted by maintaining a uniform flow of air through a wire. A positive pressure of fiber-laden air distributed above the wire and a negative pressure below result in the flow through the wire of the fiber-conveying medium. The fiber is trapped on a moving wire and held by the vacuum under the wire. It can be seen that this type of felter follows the principle of a wet process forming machine, but with the substitution of air for water.



Snowfall Type Felter

A commercial installation in this country of a vacuum-type felter is at the hardboard plant in Klamath Falls, Ore. In this installation, metered fiber is conveyed by air to a felting head suspended above the wire, and this head is maintained under a slight positive pressure. The felting head contains a rotating brush, which assists in maintaining a uniform distribution of fiber-in-air within the head, and keeps open the perforated plate that forms the bottom of the head. The perforations are uniformily spaced over the width of the wire. The fiber, under positive air pressure, flows through the holes and is trapped on the wire as the air flows through the wire to the vacuum box below.

Air is easily deflected and eddy currents are difficult to control. Under changing atmospheric conditions, fiber moisture content, or fineness of grind, the vacuum felter requires skilled operation. It does lay down a uniform fiber mat, and proof of this is evident in the lack of a shave-off or side-trim saws prior to pressing.

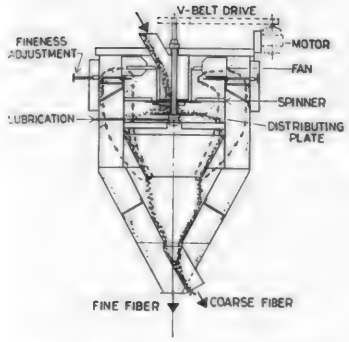
A vacuum-type felter readily lends itself to multiple units, which allow the mat to be built up in layers and permit variation in the fibers and resin content used for the core and surfaces of the board.

Other vacuum felters that follow similar principles but are quite different in mechanical design have been operated on a pilot-plant basis.

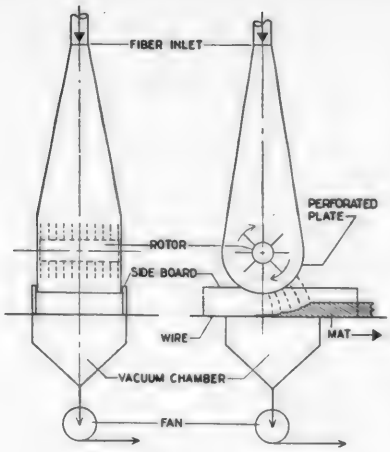
Pre-Pressing and Mat-to-Caul Mating: A dry-fiber mat, as felted, is generally quite thick and fragile. Sufficient pre-pressing must be done to consolidate the mat so it may be handled. Presjent commercial installations are all similar in that the mat is compressed between rubber belts backed up by pressure rolls. As air is squeezed out, it must escape through the mat. Rate of compression must be controlled so that the escaping air does not attain sufficient velocity to disturb the surface fibers. This problem becomes more acute as felting machine speeds increase.

Mat-to-caul mating is accomplished either by use of a vacuum transfer or by mating the moving mat to a synchronized caul by sliding the mat over a plate and onto the caul beneath the mat. The vacuum transfer is satisfactory until felting machine speeds are increased to the point where there is insufficient time between mats to pick up the mat, move over the caul, deposit the mat on the caul, and return. Beyond that speed, the second method or a better one, yet to be discovered, must be used.

Pressing: There are as many variations in pressing techniques as there are hardboard products and operators. Basically, the operation is the same in all plants and all processes. The press must be loaded and closed, the mat consolidated to fix board thickness and density, moisture driven off, binders (natural or synthetic) must be set, and the press opened and discharged.



Fiber Classifier, "Williams" Type



Vacuum Type Felter

In general, presses for dry processes must be built with more daylight than those for wet mats, since the dry mat cannot be pre-pressed to as thin a mat. There is a limit to the speed at which a dry-process press can be closed because the outrush of air between platens must not disturb the dry fiber.

Pressing cycles are generally shorter in dry processes than in wet processes; consequently, fewer presses are required for equal tonnage.

Simultaneous closing is desirable on a dry-process press. It permits rapid closing of the press, and eliminates differences between bottom and top opening boards that result from unequal drying out of the mat during closing.

Resin Addition: Resin may be added in a dry process at several points and by various means. It may be added to the chips ahead of the fiber-making equipment, at the time of initial fiberizing, during a fiber-conveying step, or by spraying on the fiber in a special machine called a blender. The object is to attain the best possible distribution of resin on individual fibers. The point of greatest fiber agitation seems to be the best point for resin addition.

Advantages and Disadvantages of Dry Processes

The most obvious, but not necessarily most important, advantages are these which stem directly from reduction in the water required. The water requirements of a wet process plant is approximately 10,000 gallons per ton of board production. Water usage for a dry process hardboard plant would be a minimum of 1,500 gallons per ton.

Most of the water entering the process must be disposed of and constitutes an effluent problem. The reduction of effluent volume by 85 percent can, in itself, dictate the necessity for a dry process.

The wide difference in water usage permits the dry processes to effect a saving in capital cost by avoiding expensive water- and effluent-handling and treating facilities. Also contributing to a lesser capital cost is the elimination of stock chests, substitution of sheet metal ducts for piping and valves, the lesser cost of a dry process felter over the wet process forming machine, and the lesser cost of a fiber flash drying system over a tunnel-type dryer.

Another advantage in the dry process is the increased yield. Dry process plants indicate yields from 90 to 95 percent, as against yields in the wet process hardboard industry of from 80 to at most 90 percent. Increased yield obtained in the dry processes is obtained at some sacrifice, because some of the material that makes up the increased yield does not improve board properties.

It is safe to state that boards produced by the dry process show improved machinability and internal bond strength, and poor dimensional stability when compared with wet process boards. The relative importance of these board properties is entirely dependent upon the end usage for which the hardboard is intended.

An advantage of the dry processes is the ability to produce a wider product range of hardboards. Thicknesses at standard densities have been produced that seem to be beyond those which can be formed on wet-process forming equipment. Special surfaces and multilayer boards with variations in fiber and resin in the layers are easily accomplished with dry process equipment. These permit production of a wide range of special board with properties specifically tailored to the end-use requirements.

It must be freely admitted that one of the wet processes can and does produce a much wider range of products than has been made in any dry process. The wet-formed dry-pressed process produces both soft and hardboards with forming equipment common to both. The versatility in product range of this process is accomplished at considerably increased capital cost, because extensive equipment is required for each type of board.

The dry process can be claimed to be more easily adapted to S2S hardboard manufacture, primarily because of the reduced equipment required when pressing S2S boards from dry mats as compared with the wet-formed dry-press process.

All these advantages were not obtained without some sacrifice. At present, a serious disadvantage in dry processes is the difficulty of process control. One hundred years of know-how was discarded in the switch from the wet to the dry process. Most of the specialized laboratory equipment now used to assist in process control of the paper industry is not easily adapted to a dry process. It is difficult even to obtain a representative fiber sample in a dry process plant. One can safely assume that a sample taken from an agitated stock chest is representative of the stock stored in that chest, but no grab sample taken from a pneumatic conveyor or from the felting machine is representative of the fiber produced between samples unless the process is in control. Time will improve the situation, for many are constantly working to improve process control techniques in the dry fiber processes. Meanwhile, dry process hardboard plants run a higher percentage of rejects than is common in the hardboard industry.

The second disadvantage inherent in the dry process is the inability to store dry fiber in any appreciable quantity. The physical dimensions of a storage bin required for a material with a bulk density of 1 to 2 pounds per cubic foot precludes any stock storage or reclaiming of material momentarily diverted from the process. Five minutes production of fiber might require 1,500 cubic feet of storage space. Once stored, it is difficult to feed fiber uniformly back to the process by mechanical means. Existing dry process hardboard plants, of necessity, require that the process be continuous from the fiber-making equipment to the press loader. Small delays anywhere along the line result in a shutdown all the way back to the chip feeder, or else fiber must be disposed of as it is produced. Disposal is usually by burning in the powerhouse or in a waste burner. Unanti-

cipated diversion of dry fiber at momentarily large rates causes many problems at the boiler or burner unless the fiber can be mixed with other fuel so that it may be mechanically conveyed and the supply spread more evenly.

A disadvantage to both the designer and operator of a dry process plant is the lack of standard equipment for some of the operations. It is often necessary to adapt to dry process use equipment from the wet process or from other industries. Where such equipment does not prove satisfactory, it is necessary to design machines for the specific use intended.

Over the years, equipment used in wet processes has been developed to a high degree of reliability. When such equipment is modified for use in a dry process, or when special machines are built, reliability often suffers for the first few years of operation.

The operator also has the disadvantage of being unable to readily obtain experienced personnel. Dry process hardboard plants are so relatively new that trained operators are seldom available. A wet process plant may not be able to obtain operators with previous experience on hardboard machines, but can usually obtain persons trained in paper making with a basic knowledge and skill in handling the type of equipment used.

In a dry process plant, it is necessary to guard constantly against fire. This can probably be said of all plants and all processes, but the hazards are greater in the dry fiber industry for obvious reasons.

Conclusions

Where water supply and effluent problems are more severe than normal, the choice of a dry process may be mandatory. All future dry process hardboard plants will not be inspired by such conditions. however.

Bowater Board Company plans to construct a dry process hardboard plant adjacent to a 400-ton sulfate pulp mill. Water and effluent facilities for the pulp mill were not yet designed when the decision was made to use a dry process, and could have been economically enlarged for a wet process. Bowater has had many years of experience in papermaking and operates two wet process hardboard plants in England. Why then a dry process?

Two reasons stand out—a lower capital investment and the ability to produce products with properties the customer requires for a specific hardboard application. Future industrial uses will require that hardboard be produced to many and varied specifications. The process must be capable of producing to these specifications.

Discussion

Dr. J. d'A. Clark (Changewood Corp.): In felter design, the best types are those which do not require scalping and returning excess to bins, as is required at Sandpoint, Idaho. Also, the special chest design for board involving circumferential feeding to the chest and radial withdrawal, so as to get a perfectly mixed supply for the felters, is of very great help in making a uniform product.

H. A. Lenderink (L-M Forest Products): What is the difference between dry process hardboard and particle board? For example, Lebanite was omitted from your paper as a hardboard. Is Cascade Plywood processing hardboard or particle board? What is the dividing line?

Mr. Robinson: The Cascade Plywood process is the dividing line. I consider anything coarser as particle board, anything more fibrous as hardboard.

Neal Reyburn (Home Bldg. Corp.): Is there any possibility of producing a hardboard 8 feet wide?

Mr. Robinson: Yes, in Germany they are now making hardboard 7 feet wide, so one could go to 8 feet.

A. L. Mottet (Long–Bell Div., International Paper Co.): You mentioned the use of direct-heat flash drying for the drying of fibers for the dry process. Is there any sacrifice of strength properties of the board by the use of this method of heating?

Mr. Robinson: There may be a slight loss in strength, but we were unable to determine definitely if there was or was not.

P. H. McCormack (National Starch Products): Can you control ignition of fines passed through the flame of direct-fired driers? Is any material lost in this way?

Mr. Robinson: There is a small loss in the drying process, but I do not know if it results from ignition of fine fiber, as you suggest, or from collector losses normal to most pneumatic conveying operations. At any rate, I question whether the retention of such fine fiber would improve any of the board properties.

Harold Evans (Plywood Research Foundation): Do you have any way of dividing dry processes from wet processes as regards moisture content?

Mr. Robinson: If the fiber can be felted with air as the conveying medium, I would term the process dry, no matter what the moisture content of the fiber. I believe the term dry refers to the conveying medium, not to the condition of the fiber.

Scanning World Wide Forest Products Publications

• Germany

The Influence of Steaming on the Swelling Pressure of Wood. T. Perkitny, M. Lawniczak, and H. Marciniak. *Holz a. R. uW.* V. 17, No. 2:54. Feb. 1959 (English summary)

The swelling pressure exerted by steamed and unsteamed wood was determined instead of the traditional volumetric alteration of freely swelling wood. For this purpose, green beech wood laths were subjected to different steaming conditions and cut to samples of 30 mm by 30 mm by 20 mm. The steamed samples were immersed in water at 20° C., together with unsteamed controls at an initial moisture of 0 and 10 per cent, and were examined on their free swelling as well as their unidirectional swelling pressure.

While the definitive maximum values of free swelling were not lowered, but were even increased to some degree by the preceding steaming process, it is interesting to note that the steamed samples showed a marked and continual reduction of their maximum swelling pressure. The widely held view that the steaming of wood contributes to an increase in the dimensional stability of timber structures is confirmed by this observation.

• Japan

Physical Properties of Plywood under Low Temperature (–55° to –65°C.) Sotoshige Iseda and Yasuyuki Tsuji. *Wood Industry* (Japan), V. 14, No. 143:23. Feb. 1959. (English summary)

Many studies on the weathering resistance, fire resistance, and antiseptic-ity of plywood have been reported, but mechanical strength of plywood at low temperature has been studied very little.

In order to compare results, the experiments were performed under both normal conditions and while frozen by dry ice and ether in a Dewar's pot. The specimens set in the pot for 60 hours were picked out at random and tested while frozen.

Most of the properties of plywood at these low temperatures showed 10 to 20 per cent higher values than at normal conditions such as those reported by Dr. F. Kollmann and Mr. O. H. George. In comparing the results, only the impact strength in the frozen condition was lower than in the normal condition. This result is different from that reported in the literature by the above two researchers. This different result may contain experimental error in its process, but it is considered very interesting to the authors.

WORLD-WIDE

Forest Products News

European Wood Institutes Meet to Coordinate Research

EARLY IN APRIL of 1959 the Timber Information Institutes of Austria, Denmark, France, Germany, the Netherlands, Switzerland, and the United Kingdom, together with representatives of Forest Products Research Institutes from the same countries and observers from the timber trade, met for two days in Amsterdam to interchange information pertaining to the wood industry.

Opening the Congress, Mr. B. Poulie, Chairman of the Timber Information Institute of Amsterdam and first-day Congress president, pointed out that the frontiers of European countries are gradually disappearing. He stressed the position that the information institutes can assist research by passing on current problems to research organizations, by proffering financial and practical support to research, and by disseminating the results obtained.

The Congress adopted the following resolutions:

1. To safeguard the place of wood in the range of customary raw materials, it is necessary to inform the consumer in a sound and effective way as to the properties, the modern development and the appropriate application of wood for a given purpose. The information should be based upon the results of research, on the basis of data which must be reliable in a technical as well as in an economic sense.

2. It is of utmost importance that in every country an effective form of co-operation between trade, industry, information institutes and research institutes should be established, or further developed when in existence.

3. The information institutes and research institutes, represented at this meeting, have decided to keep close contact and to come together regularly to interchange their views, programmes, results and experiences.

4. It is decided to form a small working group to study the recommendations as given in item 3 and—recognizing the existence of other bodies formed with similar aims and objects—to submit proposals to be discussed in the next session of the West European Institutes.

An abridgement of an address given at this Congress by Ph. O. Reece, Director of the Timber Association, Ltd., London, appears in this section of the F.P.J. Other brief treatments of important lectures will appear in later issues of the Journal.

Other Developments Around the World

Nigerian Plywood Mill

D. H. Buckle, United Africa Company, London, writing in the FAO publication, *Unasylva,* describes an African plywood mill at Sapele, Nigeria. The mill, with floor space of 150,000 sq. ft., produces high-quality hardwood plywood.

The log is peeled in continuous length veneer up to nine feet wide to be made into exterior weatherproof plywood which is generally faced with mahogany, or Sapele wood, and is always made from an uneven number of plies. The adhesive used fulfils the most recent requirements of the British Standards Institute, known as the WBP test (weather and boil-proof bonded). Failing load must not be less than 200 pounds.

The sawmills and the plymill require tremendous amounts of energy which is supplied by large power stations fired by wood waste. Turbo generators provide electricity for the mill operations as well as for the township of Sapele.

A pilot plant and research laboratory with one European and one African specialist and a staff of 14 people applies research to future projects utilizing wood, tests raw materials and products under tropical conditions, and trouble-shoots factory quality-condition problems.

Europe's Forest Yield Rises 25 Percent in Past Decade

Rome, July 8—European industrial wood production has risen to about 200 million cubic metres from the level of 160 million cubic metres ten years ago, according to Mr. Egon Glesinger, Director of the Forestry and Forest Products Division of FAO, speaking at the opening of the European Forestry Commission's 10th session.

This 25 percent increase represents a value equivalent to about $800,000,000, and has outstripped the growth rate of European population. Consumption of wood per person has gone up by 14 percent.—FAO Bulletin.

Italian Semi-Chemical Pulp Mill

A modern semi-chemical pulp mill, Soc. Uti-le, Cremona, Italy, is now producing 30 tons a day of unbleached neutral sulphite semi-chemical pulp out of low-cost poplar veneer waste and poplar branches. The pulp, reported of high quality, is being used for newsprint, glassine, bleached papers, and duplex board top liner sheets.

The mill combines latest American and European machine design and equipment. Basic design is the result of pilot-plant and research work by Fiber Products Laboratory, Springfield, Ohio, and incorporates new developments in pulping equipment such as the Bauer Rapid Cycle Digester, Pressafiner, Double Disc Refiners, and Centri-Cleaners. Complete equipment was supplied by the United States Machinery Company, New York City, who also did all engineering and supervised the installation.

NEW PUBLICATIONS

Machining Properties of Eight Philippine Hardwoods. E. M. Davis and D. G. Faustino. Reprint from the *Philippine Lumberman.* Available from the Forest Products Laboratory, College, Laguna, Philippine Islands.

A Method of Calculating Internal Stresses in Drying Wood. R. L. Youngs and C. B. Norris. Describes a method developed for calculating the perpendicular-to-grain normal and shear stresses acting at any point on the cross section of a drying board. Report No. 2133.

West European Timber Industry Needs Research, Integration, Design

PH. O. REECE
Director, Timber Association, Ltd., London

THE TIMBER WORLD had a delayed realisation of the need for more research and more technological development. Industrial production as a whole in the United Kingdom is going up three percent a year, but timber is either standing still or falling back in different categories. The problem is—how can an old established industry compete with the modern technological advanced industries? There are three basic reasons for this competition:

Development, Production, Integration

1) Rapid development of new sources of power which almost without exception will make production of competitive materials cheaper, but will have practically no effect on timber. There will be a tremendous upsurge of development in nuclear energy and we in Europe for the first time will have available a cheap and plentiful source of power which is going to make enormous differences in the manufacture of steel, aluminium, plastics, and glass—but very little in timber.

2) The growing necessity for mass production. Mass production was regarded mainly as a method of lowering costs. Today, mass production is a social necessity as well as an economic necessity, and any material that does not lend itself to mass production is not going to do very well when the competition is really intensified. The mass production of our competitors is based on continuous processes of one kind or another, which have not yet been applied to timber in the way it will have to be if we are to succeed.

3) The question of integration. All our competitors are well integrated industries by close linkage along the whole chain, from raw materials through production, design, manufacture, and marketing. As against that, the timber industries are split up into innumerable parts; we need a greater degree of coordination among all those parts. In some way we have got to find a method of linking the timber trade and the timber manufacturers to provide enough money to finance the job that new scientists, new engineers, are capable of accomplishing. The problem is to do a good trade promotion campaign based upon a sound technology. Seven things have to be done.

Trade Production Campaign

First, we must gain an objective understanding of the raw material, *and it must be objective*. When we talk about the warmth and beauty of timber I think we are deluding ourselves. The modern age is one that is being brought up to like pink plastics. It may not want the warmth and beauty of wood. It has a different tradition already.

Second is the study of modern requirements. We have to keep in touch with what is going on in the new world, in the new industries, and with what our competitors are doing. If they are providing a new kind of service to the community, we should provide a better one. We have to do research and design, because design is one of the most useful ways of getting the results of research across into industry.

Third, it is no use providing manufacturers with only a lot of facts. He does not always know how to use them, and the very great need is for some midwife to bring new ideas to birth. Therefore presenting a new idea in the form of a usable unit requires the element of design.

Fourth is simply the information services, probably the best kind of publicity.

Fifth, we must not be afraid to introduce new industries when they are necessary. In the U.K. we have created what is virtually a new industry in timber engineering, based on modern research.

Sixth, we have to cut out waste. We have not yet reached the cellulosic world, simply because petroleum has beaten us. A number of reasons are important. An oil well no more than two feet across is producing 700 tons of raw material every day. To get the same amount of raw material out of a forest, you need several hundreds of square miles, with all the problems of extraction and waste. We cannot afford a 75 percent waste when the petroleum industries operate at less than one percent waste.

Finally, we want adequate publicity and marketing. We have got to appeal to the consumer, and his preference will be determined by the cost, performance, and marketing of the finished product, not by the intrinsic properties of the raw material. We have got to look again at design and production. The costs and performance of the finished product are a direct reflection of the stage technological development has reached; this in turn depends on the extent to which the results of research can be successfully applied to improve design and production.

How Timber Trade Invests

The T.D.A. receives £80 thousand a year direct from the timber trade in addition to State money that is applied only to research. The timber trade money goes into production, services, and sales.

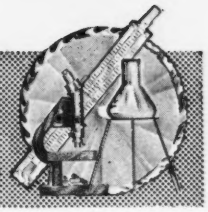
By production I mean the production of ideas including research, experimental development, and design. Services include advice to the customer about the best ways to use wood. In addition we have central advisory services in building, engineering, and biology. We deal with 75,000 inquiries every year. Also we have a systematic course of training in 50 to 60 technical colleges, with over 2000 students. These students take a 3-year course in timber technology and they can work for a higher certificate in timber technology. Any of our manufacturers can send people to us for training in assembly techniques, in glued lamination, and the erection of timber structures. Every year we issue a quarter million booklets or papers.

Sales includes advertising, exhibitions, films, and articles in the press. Advertising is almost wholly restricted to architectural and engineering papers. We have given an average of about 800 film shows every year for the last four years, and now have started to make our own films from our research activities.

Research Projects

We have given more attention to research in roofing techniques than anything else. The tendency in Great Britain is to put up single story buildings. Not so long ago the cost of a roof was under 10 percent of the cost of a building. Today it is over 30 percent. Recently we have developed the modern timber shell roof by which we can save over 30 percent of roofing costs. The shells now being developed are the hyperbolic paraboloid and the conoid. In hyperbolic paraboloid construction, a panel 25 ft. square would have no beams at all, but simply two layers of 1-inch boarding. The biggest structure so far is 114 ft. square with a column in the middle of each side. We are constructing a railway station at Manchester which has three conoid shells of over 100 feet span and consists of about 2½ inches of solid wood.

Abstracting the Literature



Adhesives

Narayanamurti, D., and Das, N. R. Tannin-formaldehyde adhesives. *Kunststoffe* 48, no. 10: 459–62 (Oct., 1958). [In German]

Warm-water extracts (containing 86% tannin) of the bark of tropical and subtropical trees *(Acacia mollissima, Callitris* sp., *Bruguiera,* and *Ceriops candolleana)* were concentrated to 35–40% and reacted with formaldehyde or paraformaldehyde and sodium hydroxide to yield technically useful adhesives compatible with phenol-formaldehyde resins. Typical adhesives contain 1–1.5% sodium hydroxide, 15% paraformaldehyde, and 1% phenol (as preservative), based on the weight of the dry extract solids. Wood meal can be used as filler. Among other applications, the tannin-formaldehyde adhesives were used successfully to laminate bamboo mats as intermediate layer between wood veneers. 11 tables, 4 fig., 2 ref. [A.B.I.P.C., 29:7]

Sheeran, N. J. Laminating adhesive and method of producing the same. *U. S. patent* 2,870,034. Filed April 1, 1957. Issued Jan. 20, 1959. 8 claims. Assigned to American–Marietta Co. [Cl. 106–124] M. 1673.

A method of making a rapidly heat-curable glue for paper-to-paper and paper-to-wood laminating comprises forming an aqueous mixture of spray-dried soluble blood and china clay; adjusting the pH of the mixture to 8–10.3 by adding sodium silicate, sodium hydroxide, or the like; and maintaining the glue near room temperature until the glue is spread. 1 table, 1 fig., 3 examples. [A.B.I.P.C., 29:9]

Hardwood Genetics

Joranson, Philip N. Improvement of hardwoods through genetics. *Pulp Paper Mag. Can.* 59, no. 10: 193–201 (Oct., 1958).

Significant advance is recognized in essential aspects of forest tree improvement by genetic means, in both fundamental and applied areas and in propagational and evaluative technique. Except for the genus *Populus,* the species involved have been mostly coniferous. However, there are important carry-over values of a general sort which will facilitate and accelerate genetic improvement programs with hardwoods. Opportunities for genetic improvement of growth rate and, in more detail, of pulpwood properties, are discussed, with emphasis on the need for both scientific and economic justification when a genetic program is being considered. It appears that wood property improvement ordinarily will not be justified, except in programs designed also to achieve improvement in growth rate. Various physical, chemical and anatomical variables which may be subject to genetic influence during wood growth are seen to affect three areas of industrial interest, namely, yield of pulp, factors influencing processing cost, and sheet properties. 1 table, 1 fig., 33 ref. [A.B.I.P.C., 29:7]

North American Hardwoods

Love, D. V. The distribution and availability of hardwoods in North America. *Pulp Paper Mag. Can.* 59, no. 10: 188–92, 222 (Oct., 1958).

Statistics concerning the area of hardwood forests and the inventory volumes, growth, and utilization of hardwoods are summarized. Brief comments on the various regions of North America are included in general statements made regarding the factors deciding the availability of wood, land area available for hardwood production, hardwood inventory and growth, growth and allowable cut, and species distribution in the commercial hardwood regions. It is concluded that hardwoods can be cut commercially for pulp production in eastern United States, including the South, in eastern and central Canada, and in the prairie provinces. The annual allowable cut of hardwood not presently utilized in these regions exceeds 51 million cords. In the United States, the oaks are the most prevalent species, followed by the beech and maple group, which includes yellow birch. In Canada the principal species is poplar, especially in the prairie and central regions; in the East the beech-maple group supersedes the poplar. White birch makes up a large part of the poplar-birch type in eastern Canada. 5 tables, 6 fig., 4 ref. [A.B.I.P.C., 29:7]

Herbicides

Kovalev, V., and Tishchenko, D. Herbicides from phenols obtained by wood pyrolysis. *Zhur. Priklad Khim.* 31, no. 11: 1708–15 (Nov., 1958). [In Russian]

The phenolic fraction boiling at 180–210°C., obtained by dry distillation of wood, has a constant composition (irrespective of the type of wood) and contains about 25% phenol, 10% *o*-cresol, 30–40% guaiacol, and smaller amounts of *p*-cresol, *o*-ethylphenol and xylenols. A mixture of chlorophenoxyacetic acids, obtained from the phenolic fraction by condensation with sodium chloroacetate followed by chlorination, was found to have selective herbicidal properties, destroying dicotyledons, including many species of hardwoods, but was harmless to softwoods and grasses. Tests proved that the new herbicide is highly effective both as a weed killer and as a stimulant of cereal growth. 4 tables, 3 fig., 12 ref. [A.B.I.P.C., 29:7]

Fiberboard Sheathing

Neisel, R. H. Racking strength and lateral nail resistance of fiberboard sheathing. *Tappi* 41, no. 12: 735–7 (Dec., 1958).

Racking and lateral nail-resistance tests were run on 4 by 8 ft. sheets of $\frac{25}{32}$-inch fiberboard sheathing. Data indicated a linear relationship between ultimate racking load and laterail nail resistance. The relationship was not similar to that obtained previously, but results from two test series indicated that a valid common relationship existed. Several differences in testing procedure between the two test series included the type of nail used, the sequence of loading during the racking test, the location from which lateral nail-resistance samples were taken, and the testing speed during the lateral nail-resistance test. 3 tables, 2 fig., 1 ref. [A.B.I.P.C., 29:7]

Hardwood Lignin Chemistry

Pepper, J. M. Chemical aspects of hardwood lignins. *Pulp Paper Mag. Can.* 59, no. 10: 253–9 (Oct., 1958).

A review of the knowledge of hardwood lignins is presented, with particular emphasis on aspects where further research is indicated. The discussion of the structure of lignin is divided into four parts, according to the source of the information: the isolation and subsequent chemical or physical-chemical investigation of a lignin substance, the degradation of protolignin or isolated lignins and the subsequent isolation of identifiable products of smaller molecular weight, biogenetic studies using model substances as lignin precursors and radioactive tracer techniques, and miscellaneous observations particularly using lignin model compounds. Evidence suggests that, as part of the wood cell, the lignin complex is chemically stable and only as a result of its liberation does it become chemically reactive. It may be that much of the knowledge of the fundamental chemical composition must result from a study of chemical changes and extrapolation rather than absolute measurement. 5 tables, 53 ref. [A.B.I.P.C., 29:7]

Hemlock Chemistry

Kurth, E. F. Chemical analyses of mountain hemlock. *Tappi* 41, no. 12: 733–4 (Dec., 1958).

Chemical analyses were made of mountain hemlock *(Tsuga mertensiana)* wood and bark. The wood had an extractive content of approximately 6.6%, whereas samples of the bark had extratictive contents ranging from 29.4 to 39.5%. The inner bark had a smaller amount of extractives than the outer bark. A tannin content of 15.8 to 21.0% was found for the bark. The purity of the tannin extract ranged from 72 to 77%. Other extractive compounds found in the bark were waxes, a purple-red coloring matter, and protocatechuic acid. The ether extract from the inner bark appeared to contain *d*-catechin and *l*-epicatechin. 4 tables, 4 ref. [A.B.I.P.C., 29:7]

Machine Polishing

Polishing by Machine with Steel Wool. *Holz im Handwerk,* October 1958, p. 7 (in German).

For certain types of matt finish, fine steel wool is used. By hand, this process takes a long time, especially when large amounts of furniture are concerned.

A firm in Germany has now developed a steel wool mesh bonded to linen for use with belt sanders. The belts have proved extremely useful, particularly for cutting down synthetic resins and polyester lacquers. They can be used dry as well as with matting and polishing pastes and solvents. Steel and wool discs have also been produced. [F.D.C. Tech. Bul. V. 7, No. 42.]

Particle Board Finishing

Bardin, P. C. Preparation of Particle Board for Painting or Finishing. *Industrial Finishing.* V. 34, No. 9, July 1958, p. 60.

Wood particle board contains voids much larger than those in wood or hardboard. It

usually contains, also, moisture control additives. These two factors make the filling necessary before painting a special problem. It has been found that filler for the face of the board should be different from the one used for the edges. Also, it has been found that a special method of application is necessary, because the small amount of solvent makes the filler dry too quickly to be either sprayed or roller coated.

A satisfactory machine with 3 doctor blades has been developed. With this machine, which can coat boards up to 54 inches wide in a range of thicknesses from ¼ to 4 inches, the thickness of the filler coat can be controlled to $\frac{1}{32}$ inch. The filler dries so quickly that boards can be stacked 2 minutes after they are coated. Two coats should be applied; the first should be sanded down, and the final one brushed with a special rotary machine. F.D.C. Tech. Bul. V. 7, No. 42.

Structural Test

Structural Test of a House under Simulated General Wind and Snow Loads. D. B. Dorey and W. R. Schriever. Research Paper No. 43, Division of Building Research, Nat'l Research Council, Ottawa, Can. Oct. 1957.

This paper is reprinted from the Symposium on Full-Scale Tests on House Structures published by ASTM. It describes in full the work on the DBR experimental house and is liberally illustrated with diagrams, line drawings and photographs. [BRI Abstracts, Dec. 1958]

Debarking

Maheu, Claude E. A highly efficient mechanical debarking process. *Papier, carton et cellulose* 7, no. 4: 130–2; summaries: 146, 150 (Sept.–Oct., 1958). [In French and English; Spanish and German summaries]

The Swedish Finshyttan barking process is based on the principle of friction and consists in pretreatment of logs with water and steam, followed by actual barking in silos equipped with Archimedean screws. The logs (2 m. long) are loaded into metal tanks with gratings on the bottom, washed with water at 20°C. to remove dirt, snow, ice, etc., then treated for 100–120 min. with hot water (85°) sprayed from the top and with steam under a pressure of 1.5–2 kg./sq. cm. introduced at the bottom. The logs are cooled with water and transferred to the barking silos. The rotating Archimedean screws put the logs into motion and cause them to rub against each other. The debarking operation is carried out for 10 min. and gives a 100% wood yield. The Finshyttan barker can bark 200 cu. m./8 hr. to absolute whiteness; although designed ordiginally for softwoods, it is also well suited for handling hardwoods. 7 figs. [A.B.I.P.C., 29:7]

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Standard elements are in widths from 3 to 12 inches, and cost 5*s* 6*d* per square foot. Mhoglas can be curved to a radius of 1 inch, or made specially curved to ¼ inch radius. Main applications would be in veneering presses, and so forth. [F.D.C. Tech. Bul. V. 7, No. 42.]

Pine Chip Storage

Blackerby, L. H. Outside chip storage. *Pulp & Paper* 32, no. 10:129. (Sept., 1958).

Although predominantly associated with storage of purchased chips and chips derived from sawmill, veneer, and other wood waste, mills all over the country have become interested in the outside storage of chips derived from normal pulpwood preparation methods. A survey of western mills

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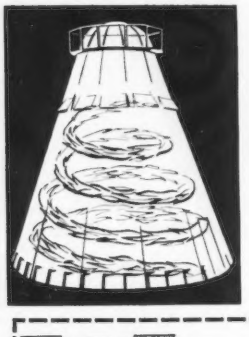

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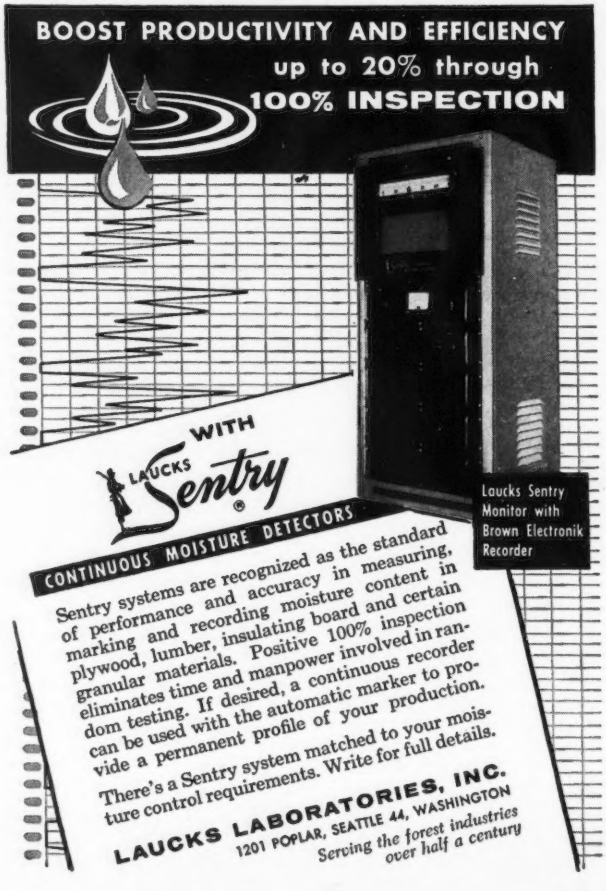
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mploying outside chip storage revealed hat chip degradation presents no serious roblem, even when storage periods range to 4 yr. The mills employing outside torage rely little on organized rotation of chip piles; storage surfaces used include d fill, black top, and bare ground; and least half the mills surveyed transport chips from outside storage directly to estion without cleaning. The survey in- ded mills using most standard pulping cesses, and the chips investigated in- ded most western commercial coniferous s. 1 table and 6 figures. [B.I.P.C., V. No. 6]

Charcoal from Wood Waste

Kozlov, V. N. Processing of wood waste and small-dimensioned wood by the pyrolysis method. *Gidroliz. i. Lesokhim. Prom.* 11, no. 25–6 (1958); Referat. Zhur., Khim. no. 22: 385 (1958). [In Russian. Abstract only available]

Production of large quantities of charcoal by pyrolysis in a new type of continuous furnace is proposed as a means to utilize wood waste and small-dimensioned timber. Charcoal is utilized in several industries, as in metallurgy (e.g., for magnesium production), chemical manufacture (e.g., carbon disulfide and carbon tetrachloride), in organic syntheses, wood products (for gas generators), and in agriculture. [A.B.I.P.C., 29:9]

Hydrolysis of Sawdust

Korol'kov, I. I., Tyagunova, Z. A., Ivlieva, E. A., Ryabovich, V. I., and Papashnikov, L. M. Kinetics of the percolation hydrolysis of sawdust. *Gidroliz. i Lesokhim. Prom.* 11, no. 6: 3–6 (1958). [In Russian]

Sawdust was hydrolyzed with 1% sulfuric acid by the percolation method under varying preheating conditions and hydrolyzate output rates. From the experimental data, curves were obtained expressing the relationship between the percolation time and the volume of liquid in the percolator, the hydrolyzate volume, and two coefficients (R_1 and R_2) proportional to acid concentration and measured time intervals, respectively. From the initial concentration of polysaccharides (cellulose and hemicelluloses) in sawdust and the values of R_1 and R_2, the theoretical yield of sugars during each time interval, and hence the total sugar yield, could be calculated. It was found that the initial liquid: sawdust ratio can be lowered from 7 to 4 (the hydrolzate volume being lowered accordingly) without any significant decrease in sugar yield. 7 tables, 3 figs., 1 ref. [A.B.I.P.C., 29:9]

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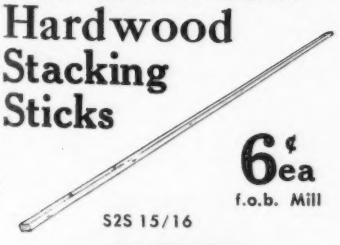

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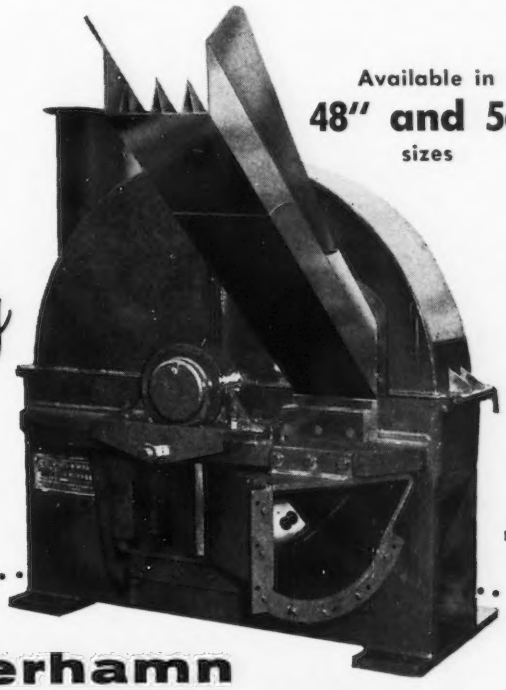

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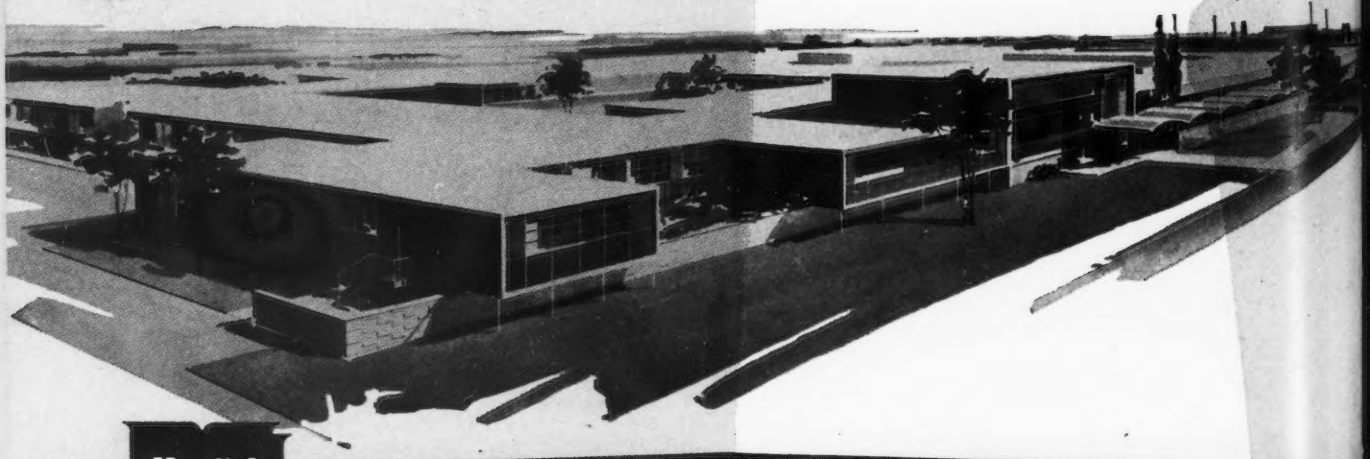

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